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(Vol. XXVIII.—January, 1893.)

FLOOD WAVES IN SEWERS AND THEIR AUTOMATIC MEASUREMENT.*

By ALVA J. GROVER, Assoc. M. Am. Soc. C. E.

READ JANUARY 4TH, 1893.

WITH DISCUSSION.

In presenting this paper, the writer asks that the many difficulties encountered may be considered in weighing the results of his investigations. Experiments of the nature of those herein described require time, money, a subject and patience. The first and almost insurmountable difficulty is the lack of time to conduct them by those who appreciate their value; the second, is that the necessary money for their successful prosecution (with no prospect of direct remuneration) puts them out of the reach of private enterprise.

Through the warm endorsement, by Mr. Andrew Rosewater, M. Am. Soc. C. E., City Engineer, of the design herewith presented, a promise was obtained from the City Council of the City of Omaha of

*Additional discussions on this paper received before April 1, 1893, will be published in a subsequent number.

$300 for experiments, with a tacit understanding that they must be a success.*

The only available point at which the experiments could be made was in an 8½-ft. circular sewer, 20 ft. under ground, at a manhole in which a ladder had to be used. Patience was required to wander down this ladder with a lantern alone at night, to see if a wheel was working before a storm.

The writer does not put the calculations hereinafter given as absolutely correct, but as approximations. Coming as they do through the medium of a novel and intricate apparatus, yet old and simple in its parts, bringing results which are at striking discord with the deductions of former experiments made by men of large experience, they are only presented for your investigation.

Taking the subject in its natural order, we will first describe—

The Rain Gauge.—This consists of a slightly modified form of the U. S. Weather Bureau standard top, shown at Fig. 1, Plate I, in plan, side and end elevations. These tops are 8.814 ins. in diameter and are filed to a sharp edge ; 1 000 cu. cm. of water are thus gathered from 1 in. of rainfall. There are two of these tops, the one conducting the rain into a copper cylinder 2 ins. in diameter and 5 ft. long; this is surrounded by a galvanized iron tube 8¾ ins. in diameter, to protect the same from heat. The rain gathered in this gauge is measured with a stick the same as at U. S. Weather Bureau stations.

The rain gathered in the other top is conducted through 60 ft. of ⅜-in. brass tubing to a register case. The apparatus in this case is shown in plan, side and two elevations on Plate I, Fig. 2. From the tube the water falls into a standard 4 000-cu.cm. jar. This jar is suspended, as shown in Fig. 3, on a pair of scales, to the arm of which is attached a glass pen. The jar is also counterpoised by an adjustable ball C.

To a long arm, suspended by two links as shown in Fig. 3, is a second ball marked C'. As the jar fills with water the ball C' is forced more and more from the plumb line, and its lever arm increases as the sine of the angle. At the same time the glass pen is moved to the left

* The actual cost of the apparatus was over $500, besides the labor of fitting and adjusting the different parts from the machinist, the tinner, the jeweler and the cabinet-maker, all of which was done by the writer, as well as the making of the glass pens and mixing of the ink.

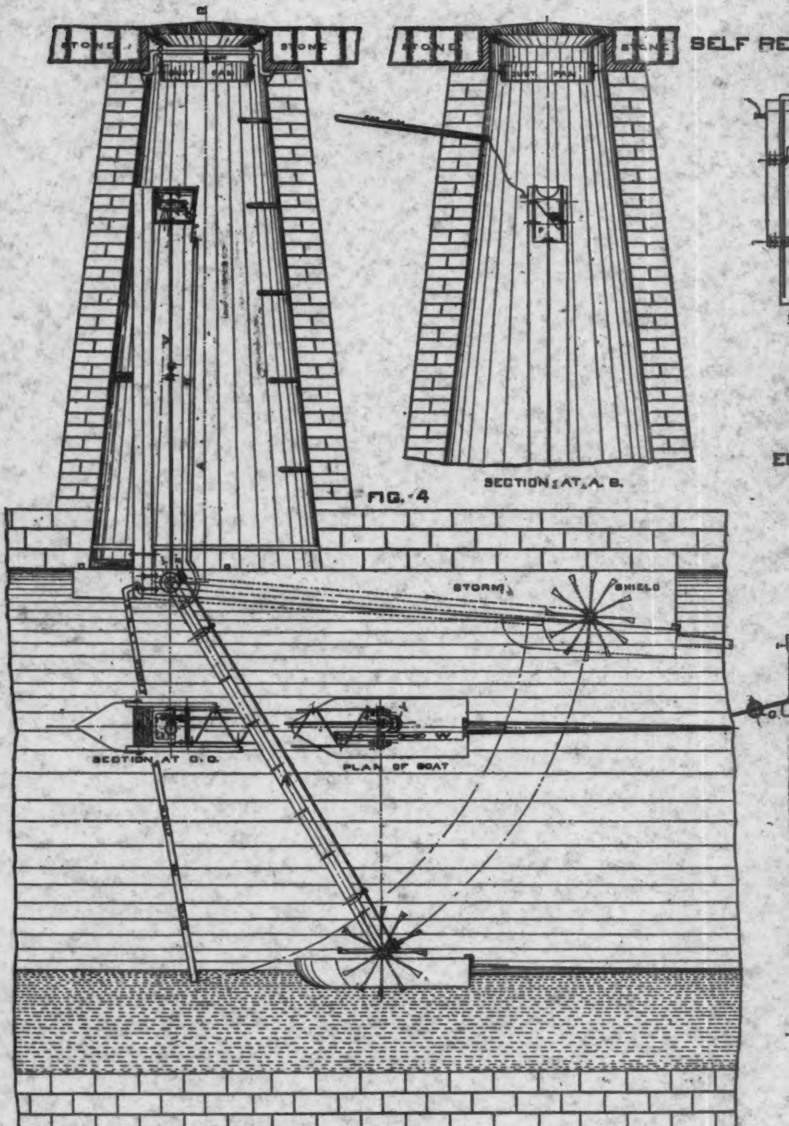

FIG. 4

SECTION OF SEWER AND MAN-HOLE
SHOWING SIDE ELEVATION AND PLAN OF SEWER GAUGE

PLATE I.
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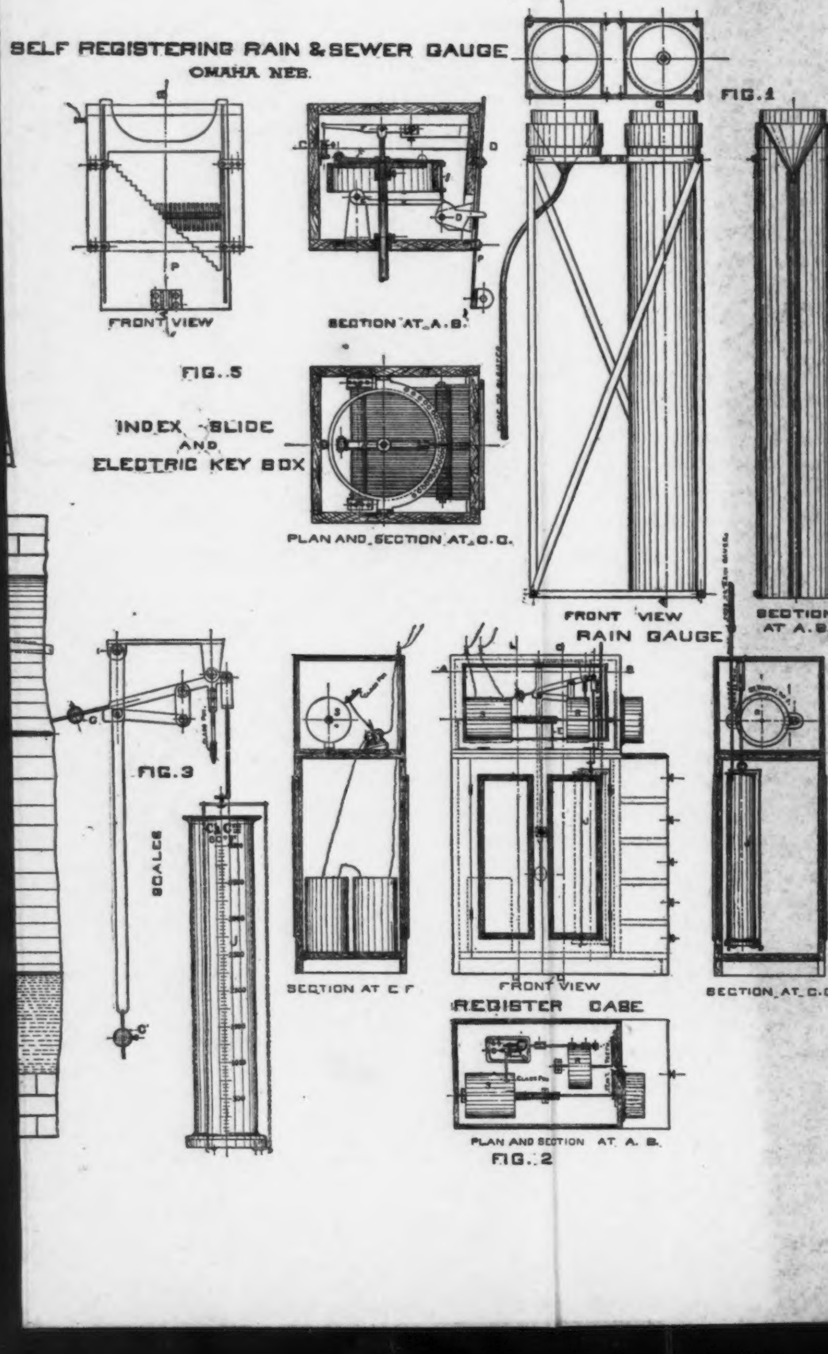
GROVER ON FLOOD WAVES IN SEWERS.

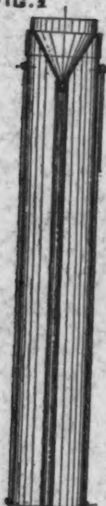


ENGRS.

2. 1

IN SEWERS.

FIG. 1



SECTION AT A.B.

IN_AT_C.D.,

and as it is pressed against a 6-in. cylinder *R*, shown in side elevation of the register case, around which suitable lithographed paper is placed, the amount of rainfall is registered.

Connected to the shaft of this cylinder by a knuckle joint is a brass gear wheel with 189 teeth, which works into a pinion with seven teeth. This pinion is connected to the hour shaft of a clock by a knuckle joint, which causes the cylinder *R* to revolve once in 27 hours. By setting the pen at the correct time as marked on the lithographed paper, the exact time as well as the amount of rainfall is automatically registered.

The Sewer Gauge.—This consists of the gauge itself, the electric key box, the register and the storm shield. The gauge is located in the sewer, and consists of a galvanized iron boat shown in Fig. 4, Sheet 1, in plan, and side elevation, 3 ft. long, 1 ft. wide and 6 ins. deep. This boat is held in place by a built arm *A*, 7 ft. 5 ins. long, attached to a stationary bracket *B*, which is firmly fixed to the arch of the sewer. The arm *A* is attached to two projecting lugs in this bracket and is free to move around its point of support.

The prow of the boat is symmetrically curved, pointed and perfectly smooth. Three inches from one side is cut a well hole *W*, 2 ins. wide and extending out to the rear. To the stern is attached a 5-ft. copper tail or counterpoise *T*, to keep the craft from getting cranky during floods. On a line dividing the boat in two equal parts fore and aft are placed two ½-in. brass journal boxes which project on either side beyond their point of attachment to the boat, and to these projections is attached the arm *A*, above described. Through these journal boxes runs a ½-in. steel shaft to which is keyed the brass hub of a paddle-wheel. Into this hub are screwed twelve ⅜-in. round iron paddles which are flattened at the outer ends, making an oval 2 x 1-in. paddle. Around this flattened end is soldered a copper plate ½ in. high at the extreme end of the paddle, and coming to a point at the shank end of the oval, making a cup very much like the heel of a girl's skate. Care was exercised that no projecting points were left to catch paper or other litter. The diameter of the wheel from tip to tip of paddle is 18 ins.

Keyed to the same shaft with the paddle-wheel is a brass worm *Z*, which works in the brass worm wheel *Y*, which has 31 teeth and is supported by a brass stirrup *S*, through which passes the shaft of the

paddle-wheel and also the shaft of the worm wheel *Y*. The shaft of the worm wheel *Y* passes over the arm *A* with suitable bearings to the bracket *B*, where a second worm *Z'* works into another worm wheel *Y'* with 33 teeth. On the side of the worm wheel *Y'* is a bevel gear with 12 teeth working into a companion with 24 teeth. This companion gear is keyed to the vertical shaft *V*, which communicates the motion through a knuckle joint to the shaft of the electric key *K* in the key box shown at Fig. 5, Plate 1, causing this key to revolve once while the paddle-wheel makes 2 046 revolutions, or while the points of the paddles travel 9 641.5714 ft.

It should be noted that the bearings of the arm *A* are concentric with those of the worm wheel *Y* at its upper end, and also with the shaft of the paddle-wheel at the boat, thus allowing the boat freedom to rise and fall with the flood in the sewer.

At a point on the arm *A*, 6 ins. from the upper point of support, is attached a connecting rod *R*. This rod extends upward into the manhole and is coupled to the index slide *P*, Fig. 4, also shown in a large view at Fig. 5. In construction, a part of this plate is cut away, and the lower diagonal line of the hole is notched with 24 $\frac{1}{4}$-in. steps, as shown on front view, Fig. 5. On each of these 24 steps rests a dog *D*, which has an extension through the cut in the plate *P*, shown in Section A, B, Fig. 5. On each of these dogs rests another dog *E*, on the free end of which sets a $\frac{3}{16}$ x 2-in. brass pin *g*. This pin passes through two holes in the rim of a brass collar fastened inside the key box, and shown in plan at Fig. 5. Each pin is thus held in place over its respective dog.

As the boat is lifted by a rise of sewage, the arm *A* is turned about its point of support on the bracket *B*, and the rod *R* lifts the plate *P*, which revolves the dog *D* by its projection through the plate ; and this in turn lifts dog *E* and pin *g*. Pin *g* is beveled on its upper end, as is also the lower part of the finger of the electric key *K*. It should be noted that this key is constructed in two parts ; one, the body of the key, being secured to the shaft *V* by means of a set screw, and the upper or finger part is hinged to the lower part at one end and passes between two lugs near the other. Thus, while the finger has to revolve with the shaft, it is free to move up and down, carrying with it the lever *F*, which works the point of contact in the mercury cup *G*.

The pin *g* being raised, the finger of the electric key has to raise

GROVER'S SELF REGISTERING RAIN & SEWER GAUGE
SHOWING DRAINAGE BASIN GAUGED

BRICK SEWERS —
CATCH BASINS ○
FLUSH TANKS •
PIPE SEWERS —

PLATE II.
TRANS. AM. SOC. CIV. ENGRS.
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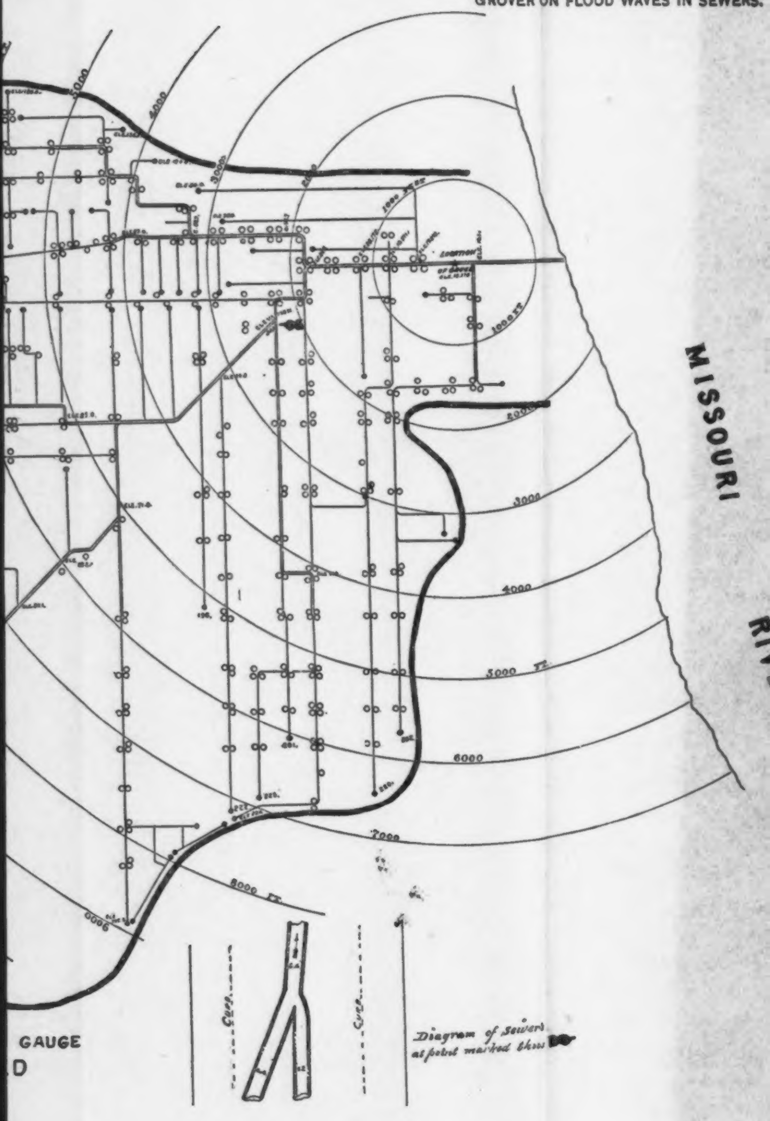
GROVER ON FLOOD WAVES IN SEWERS.

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IN SEWERS.
MISSOURI
RIVER

up to pass it, and the circuit through the mercury cup is broken. The armature in the register case, shown at Section E, F, Fig. 2, is released and the spring of the relay moves the glass pen which is attached to the armature. The pen is held down on the paper surrounding a 6-in. diameter by 6½-in. face cylinder *S*. The cylinder *S* is on a brass sleeve which moves along the square shaft attached by a knuckle joint to the same hour shaft as that of the rain gauge. On the outside of the sleeve is cut a worm ¼ in. to a turn. The stay *E*, working in this worm, moves the cylinder along at each turn, thus marking the hours in spiral lines about the cylinder. We are thus enabled to make a continuous automatic record for 26 hours, showing the depth of sewage, and the velocity of the perimeter of the paddle-wheel.

The Storm Shield.—In Fig. 4 is shown also the storm shield, which consists of a solid block of wood covered with an iron nose for a point, and two boards running back 10 ins. apart and closed at the stern end with another board, the whole being securely fastened to the arch of the sewer and stayed in the manhole. A cover is hinged at the point just ahead of the bracket *B* of the gauge arm *A*. As the flood raises the boat, it also takes along the shield cover, but as the cover is half the length of the boat shorter than the arm, and also hinged ahead of the arm, it is always a little below and ahead of the arm. Should the sewer become flooded by an excessive rain, the boat would be taken to the arch of the sewer where the two sideboards of the shield would hold the top of the wheel just below the arch, while the cover of the shield would close the opening between the boat and the nose, so that the only thing exposed to the flood would be the paddles that project below the boat.

Plate II gives the location of the gauge and some of the surrounding conditions. It is in the 8½-ft. circular main sewer, draining 2 100 acres, with slopes varying from less than 1 to 18%, and extending 11 000 ft. in its longest dimension, as shown by the concentric rings with the gauge as a center. There are also two railroads running about parallel to the main sewer extending to the southwest, and the country to the south of these roads is considerably cut up by the grading of streets. The elevations marked over the plate are those of the flow line of the sewers, and the bottom of the flush tanks. All the grades are not marked, but enough to give the general system. All catch basins and inlets are located.

The system of this district is very defective in many respects. The main sewer running southwest from the point marked ☞ being much too small for the area draining into it.

The junction of the two mains at this point is very defective, as shown in the sketch on the lower part of this plate. Much trouble has arisen there from the constant flooding of cellars during severe storms.

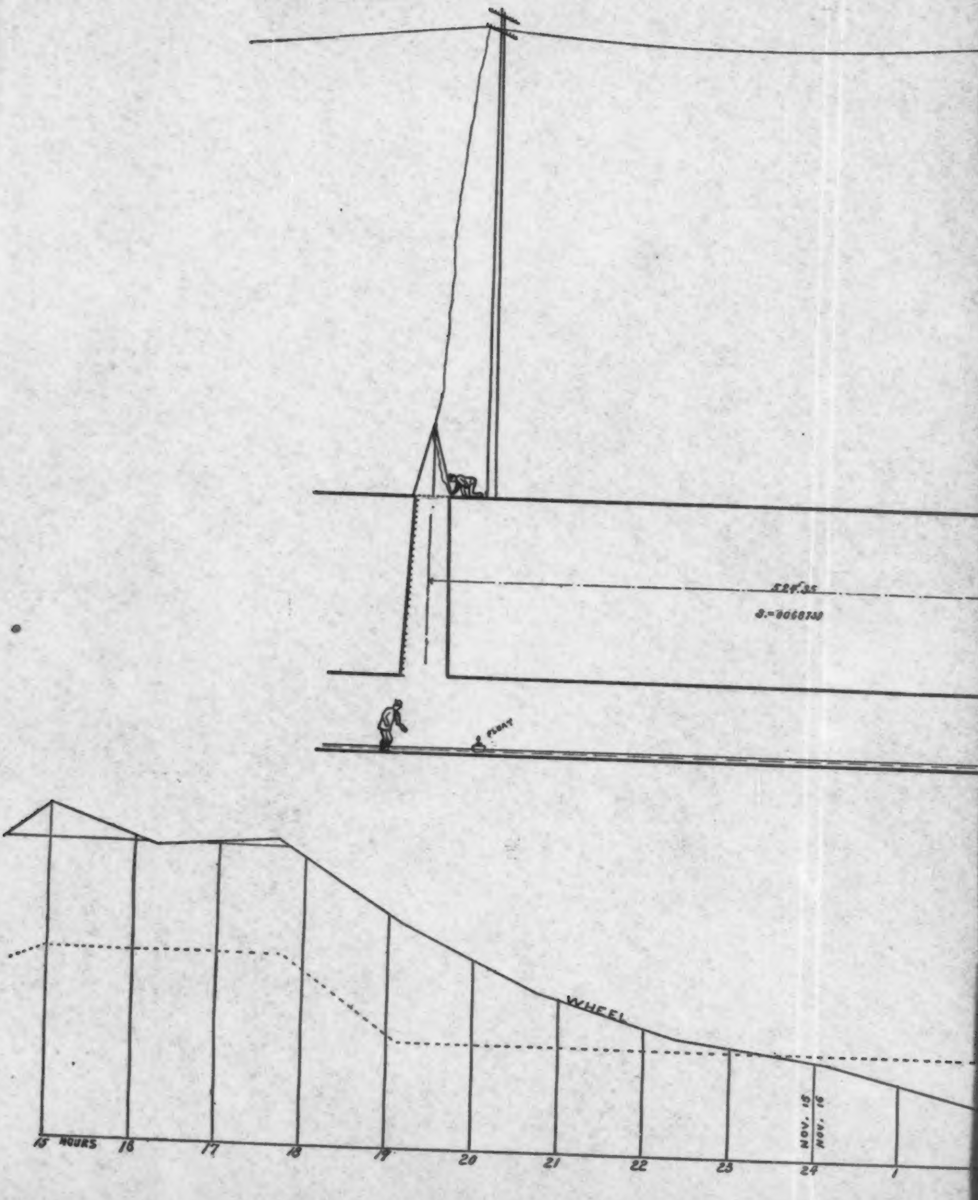
On Plate III are given the dimensions of the sewer with grades; below the gauge about 150 ft., the sewer is flattened into a semi-elliptical invert 16 x 5 ft., covered with steel beams across the top. The grade at and 417.5 ft. above the gauge is .0052719 to 1. There are about 40 000 people in the district, which, at 100 galls. per head, would make 53 333 cu. ft. per day. There are some springs along the line of the sewer, which add a small amount to the constant flow of the flush tanks; and two large breweries, as well as a number of factories and large wholesale houses, discharge the water from their hydraulic elevators direct into the sewer.

The Experiments.—Besides the daily gaugings, six rains have been gauged. The first was obtained on August 23d. The results are recorded on Plate IV. The rainfall was .77 ins., .3 of which came in 10 minutes. The summit of the flood was reached in 11 minutes after the dash was over.

A small rain of September 8th was the next registered and shows how sensitive the sewer is to rains.

The next rain gauged was that of September 27th, and as this was very successfully done, the writer will use it to explain the working of the gauge and his method of working up the data obtained. Taking the diagram of that date, we find that a registration of two pins up was made at 20 hours 55 minutes 50 seconds. At this registration we note that the time from the return of the armature at the end of the second to the time of the return of the first pin is 120 seconds. The revolutions of the paddle-wheel necessary for this is 37. The diameter of the wheel being 18 ins., this represents a distance of 174.3588 ft. which, divided by 120, the number of seconds, gives a velocity of perimeter of the paddle-wheel of 1.453 ft. per second.

Passing to the next registration of 22 hours 37 minutes 52 seconds (the time of registration is noted at the return of the armature of the last pin as it is the first one raised), we find the finger passing in 112 seconds, representing a velocity of 1.557 ft. per second, showing a



524.35
FLOAT
WHEEL
NOV. 15
NOV. 16
15 HOURS
16
17
18
19
20
21
22
23
24
1

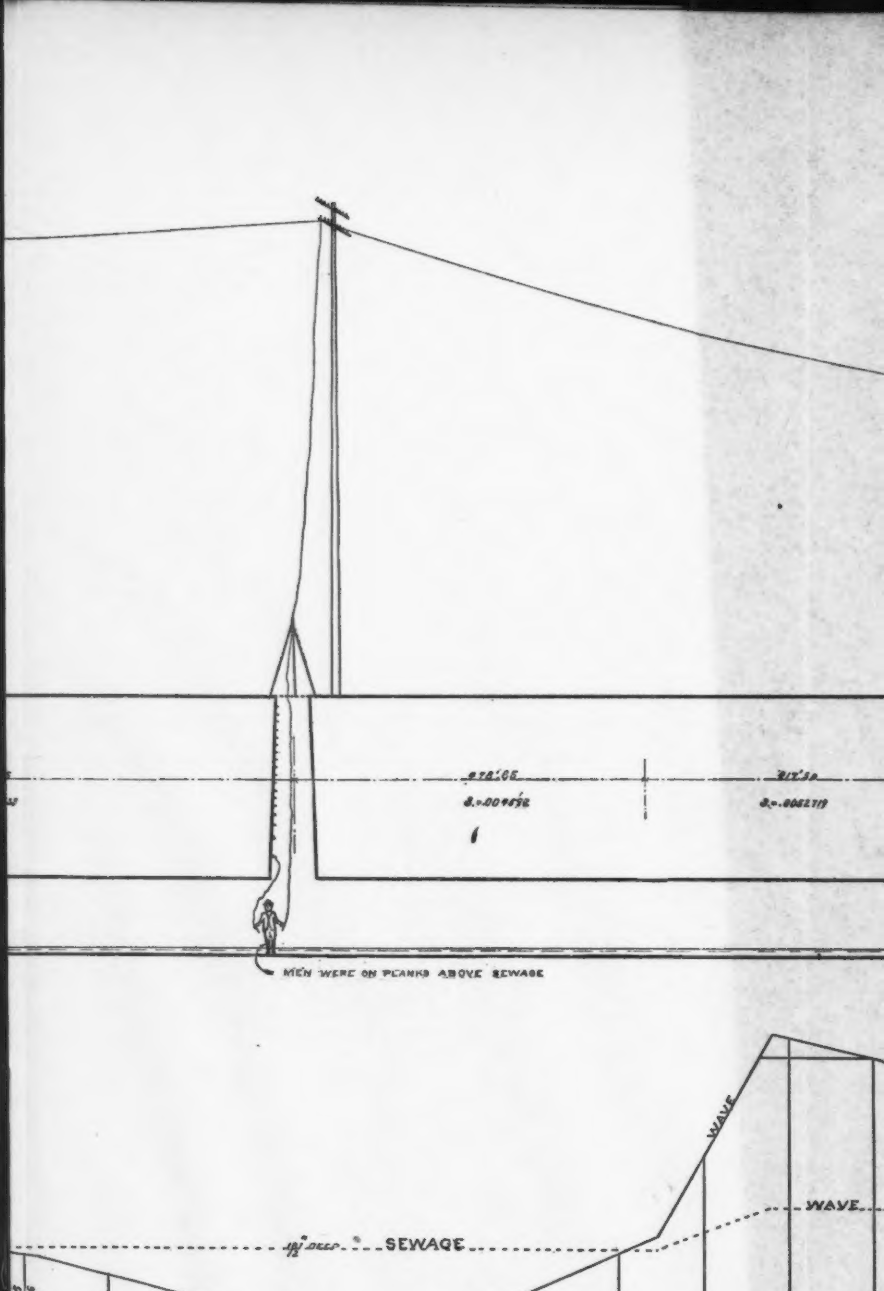

MEN WERE ON PLANKS ABOVE SEWAGE
SEWAGE
WAVE
WAVE
VELOCITY
NOV. 15
NOV. 16
24
1
2
3
4
5
6
7
8
9
10

PLATE III.
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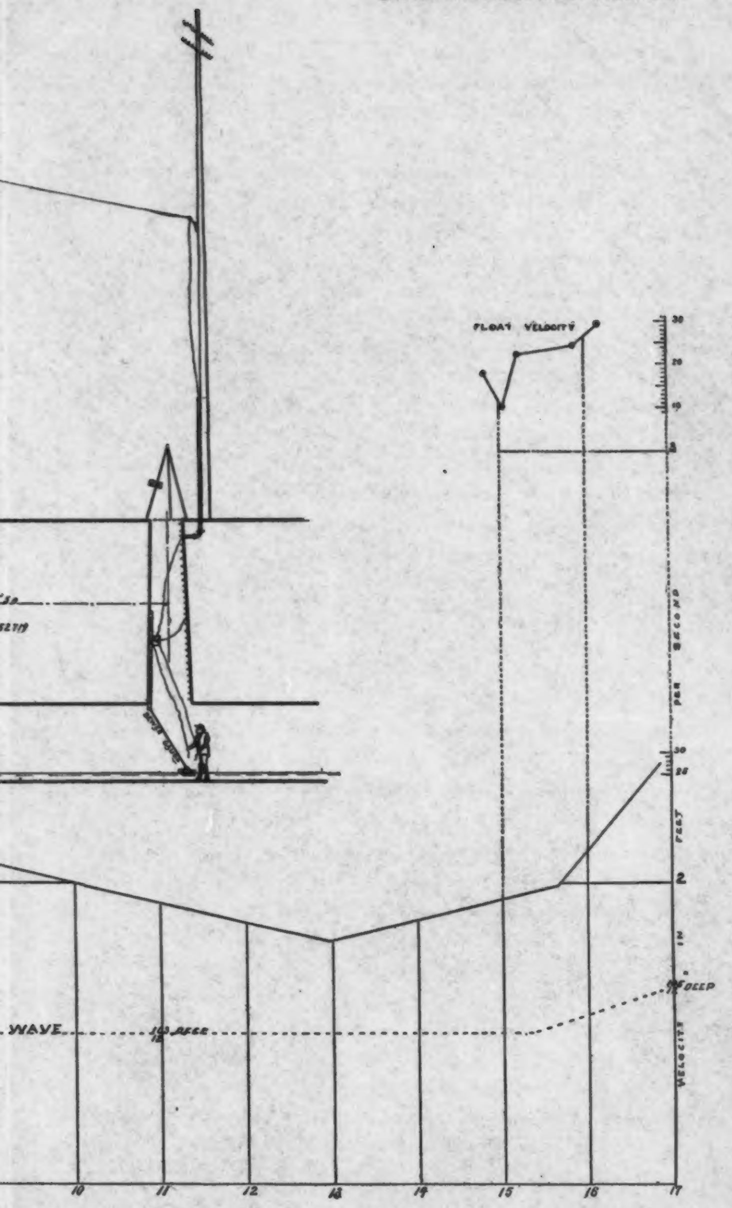


slight increase over the preceding registration. By looking at the rain diagram, we note that the pen is beginning to curve from the zero line indicating rain at 23 hours 14 minutes 48 seconds. Eight pins are registered up, or a depth of 32 ins. in the sewer. The number of revolutions of the paddle-wheel to pass the finger over eight pins is 200, or a distance of 942.48 ft., making a velocity of 11.93 ft. per second; this, multiplied by the area of cross section of the flood, gives 181.25 cu. ft. discharge per second, while the rainfall at this moment does not exceed .14 ins.

Passing to the record of 23 hours 27 minutes 24 seconds, we find 13 pins up, or 52 ins. of water in the sewer and a velocity of 13.36 ft., giving a discharge of 388.37 cu. ft. per second and a rainfall not exceeding .24 ins.

The record of 23 hours 40 minutes 20 seconds still shows 13 pins, but a velocity of 12.9 ft. per second. Again, taking the number of seconds between 23 hours 27 minutes 24 seconds, and 23 hours 40 minutes 20 seconds, or 776 seconds, and dividing the total number of feet necessary for the paddle-wheel to turn the electric key around once, or 9 641.5714, we find the average velocity to be 12.42 ft. per second, showing that at no time between these limits could its velocity exceed these shown. But taking the time between 23 hours 14 minutes 48 seconds, and 23 hours 27 minutes 24 seconds, or 756 seconds, we find the average velocity to be 12.75 ft. per second, much above the velocity of the beginning of that period; thus showing that the crest of the wave passed the gauge before or at 23 hours 27 minutes 24 seconds. That is to say, that with a rainfall of 0.2 in. falling fairly steady for 30 minutes on the 2 100 acres described above, the summit of the wave will be at the mouth when the rain ceases.

The next rain was on October 13th, occuring during the 14 days sewer gaugings, and shows almost instantaneous rise of the sewer with the falling of the rain, and the subsidence was almost as quick. The next rain of October 17th shows the same thing, only in a more marked manner, there being three distinct fluctuations of the sewer velocity to match the three dashes of rain recorded.

The rain of October 31st was 10 hours 45 minutes in falling, and shows a very large per cent. of absorption.

The following table shows the results of the six rains gauged:

Date.	Duration according to U. S. Weather Bureau. h. m.	Amount of rainfall by writer's gauge.	Duration of disturbance in sewer in seconds.	Per cent. of total rainfall discharged, registered by gauge.
August 23d........	2.25	0.77	27 963	16
September 8th......	2.35	0.13	14 575	12
September 27th....	2.55	0.32	22 853	60.6
October 13th.......	1.55	0.18	17 355	4.7
October 17th.......	....	0.40	33 050	10.7
October 31st.......	10.45	0.65	28 245	11.1

The electric part of the gauge was not working well during the rain of August 23d, and other than determining the time of the arrival of the summit of the wave, the record is hardly worthy of more study; although there is a possibility that the gorging of the sewer at the point of junction of the two south branches, and the finding of an outlet for the flood, other than through the sewer, may have resulted as recorded.

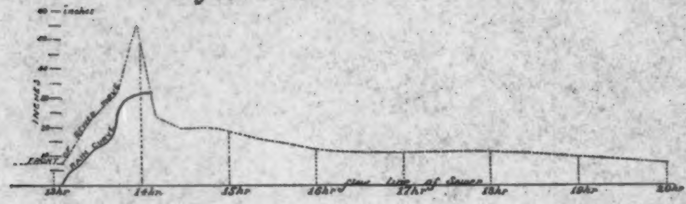
A daily normal flow sheet has been prepared, which shows the relative daily velocity of sewage, and is of interest in this connection in showing the regularity and precision of the gauge. It will be noted with what regularity the noon stop of factories and elevators is recorded. How Saturday, Monday and Tuesday are busy water days, and that the people of Omaha go to church on Sunday and stay up late that evening, all of which is clearly and regularly depicted.

A striding *Y* was set on top of the journal boxes of the paddle-wheel and by suitable levers was connected with the index slide, so that $\frac{1}{6}$-in. in height of normal flow was recorded, the results of which are platted on Plate III.

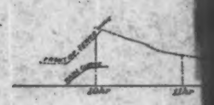
A series of floats was run on October 16th and recorded, as shown on Plate III, at the same time that the wheel was working.

Plate V gives diagrams of all the experiments, and shows the curve of areas and of wetted perimeter of the sewer, the abscissas being the number of inches in depth, and the ordinates being in the case of areas the number of square feet, and in the curve of wetted perimeter linear feet. Also, with these curves is plotted the curve of velocity as given by Kutter's formula, with the grade as found at the location of the gauge, n being assumed at .013. There is plotted also the curve

FLOOD WAVE
Aug 23rd 1892



FLOOD WAVE
Sept 8th 18



vertical scale for rain curve; ½ inch = 1

NORMAL DAILY SEWAGE VELOCITIES

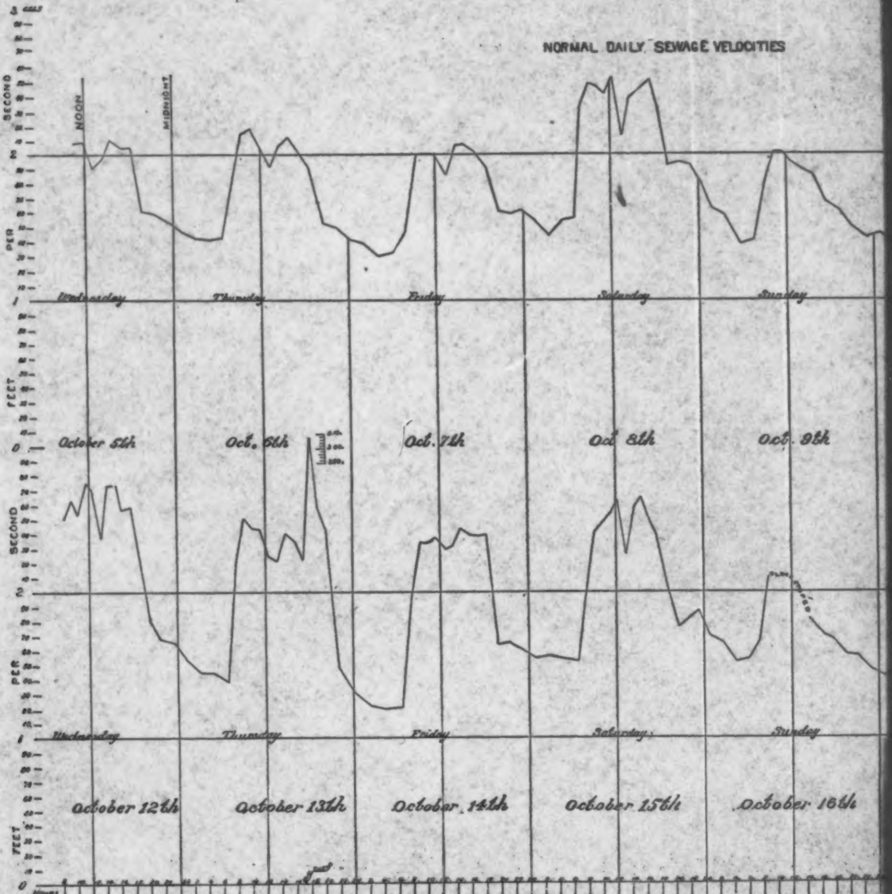


PLATE IV.
TRANS. AM. SOC. CIV. ENGRS.
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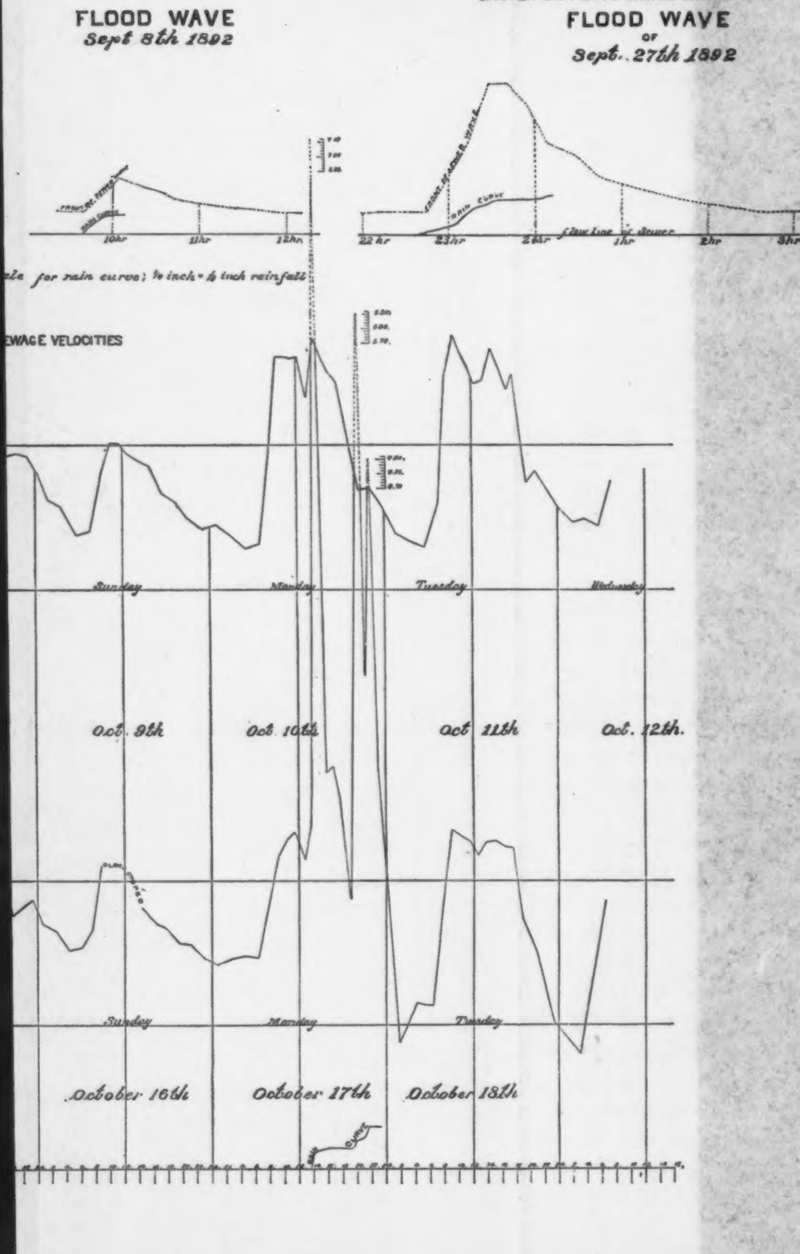

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of velocity given by the formula of Fteley and Stearns, of Boston, found by experiment on the Sudbury aqueduct. The experiments by the writer are shown by round circles connected with straight lines. Two curves have been traced, one the velocity of the front of the wave or maximum velocity, and the other, the lower velocities apparently of the back of the wave. The point which the writer wishes to make in this connection is, that the velocities which he has used in determining his quantities of discharge do not exceed those of well-known formulas.

The curves above these are those constructed by the aid of Mr. Kuichling's deduced formulas of Hawksley, McMath and Adams, also Burkli-Zeigler's well-known formulas. These deductions were published in the *Proceedings* of the American Society of Civil Engineers in 1889, a copy of which was kindly furnished the writer by Mr. Kuichling. The grade used in the construction of these curves was 2%, which is possibly too small, but any grade which could be applied to this district in these formulas would have no material effect on the deductions of the gaugings, which are shown in the curve above those of the formulas.

Taking the discharge given by these formulas for .24 ins. of rain in this district, the largest is that of Hawksley at 158 cu. ft. per second, while the record of these gaugings with the daily normal sewage deducted is 385.73 cu. ft. per second for .24 in. of rain falling in 30 minutes as already shown.

The writer puts these experiments and suggestions before the Society as an amateur in hydraulic engineering, and asks for them a fair hearing, and a just criticism. All he claims is an honest endeavor to stimulate to discovery the true relation between rainfall and discharge of flood waves through sewers, and he firmly believes that earnest experiments will soon pass into obscurity any formula for this relation which does not take into its make-up the intensity of rainfall per second.

In closing he wishes to express his appreciation of the valuable assistance rendered by Mr. J. McLearie in the preparation of the drawings of the gauge which enables him to present so complete a detail of the apparatus.

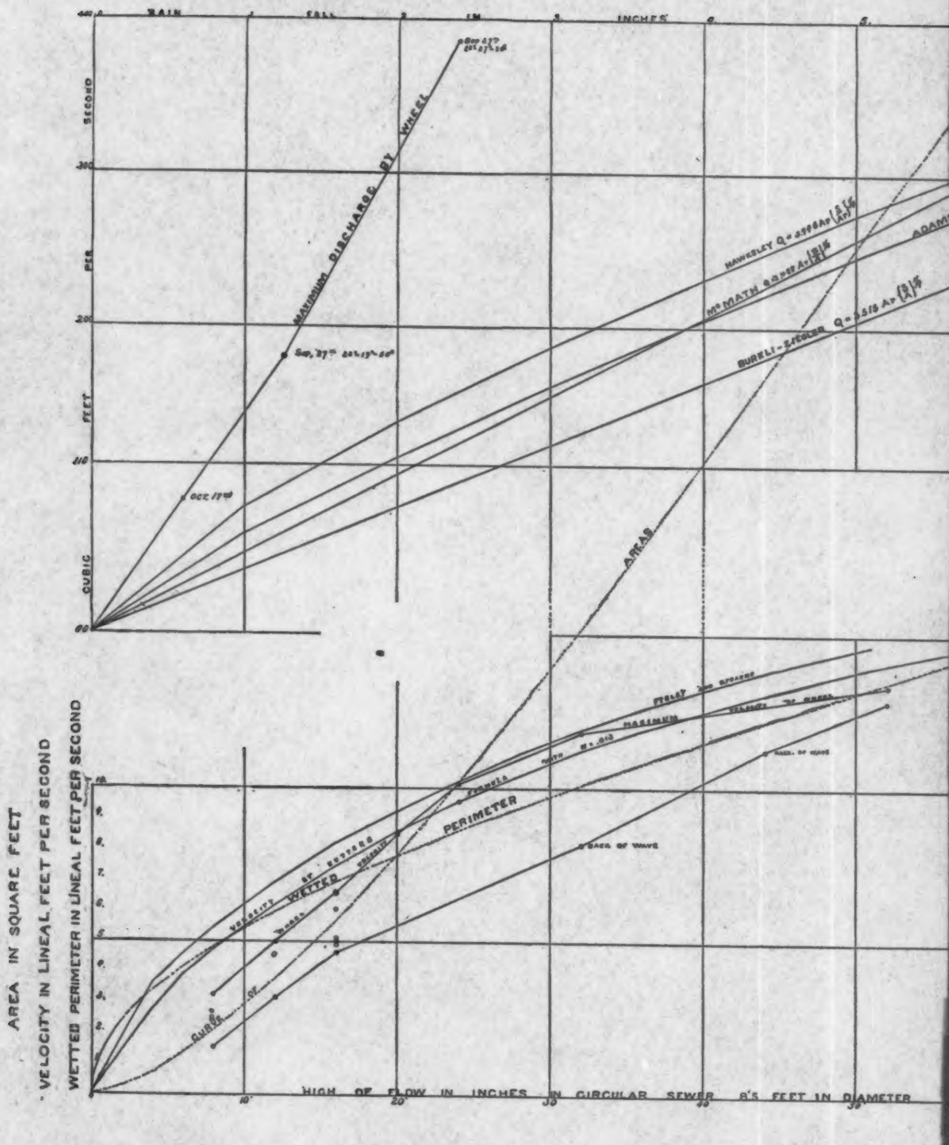
DISCUSSION.

Clemens Herschel, M. Am. Soc. C. E.—Mr. President, speaking on the paper, at your request, I have, for the paper in general, nothing but words of praise. The mechanical part of the apparatus described seems to have been gotten up with a great deal of ingenuity, and the intent is, of course, highly commendable, and in the line of what we all desire. You will notice how this engineer has put his hand deep down into his own pocket in the cause of science, and for the advancement of the profession, and, of course, that also is a thing we should applaud.

I would only like to have one question conveyed to the author of the paper. If I have understood the paper aright, to convert revolutions of the wheel into velocity, he has assumed that the velocity described by any point on the wheel truly represented the velocity of the water at the point where was placed the wheel. If that is the case, you will see at once that there is a correction to be applied. There is what is called the slip of a screw or paddle-wheel, the correction for which seems to have been omitted in the paper. This wheel, that indicates the velocity of the water coming through the sewer, is essentially a wheel such as is used in the current meter; it is much like the current meter that was used on the Connecticut River by the United States engineers. To use such a wheel, so that it will indicate the velocity of the current, it is necessary to rate the meter, which is usually done by dragging the meter through still water, instead of suspending the meter in the current and allowing the current to revolve it. A method can be devised of rating a current meter in running water, and with the meter held still, but in that case it would be necessary to meter the water some other way. For the apparatus described here, it would seem that the best way would be to take this little boat that is shown on the drawings and drag it through still water at various rates of speed. Apparently that process has been omitted. Whether I have read the paper aright in that regard, I do not know, but should like to have that point brought to the author's attention and let him say. Beyond the point alluded to, I think the paper is a valuable one.

Alva J. Grover, Assoc. M. Am. Soc. C. E.—Mr. Clemens Herschel asks if the paddle-wheel used has been rated, and if the necessary corrections have been made in the calculations.

This has not been done in accordance with the principles of vane wheels, as detailed and formulated by Weisbach and others, not because it has been considered unnecessary—for the friction in this wheel is an appreciable amount—but because of the difficulty of rating it.



RAIN FALL IN INCHES
CUBIC FEET PER SECOND
MAXIMUM DISCHARGE BY WHEEL
Sep. 27th
Oct. 17th
HAWKSLEY
McMATH
ADAMS
BURKLI-ZIEGLER
AREAS
PERIMETER
WETTED
VELOCITY OF GUTTERS
MAXIMUM
BACK OF WAVE
CURVE OF
HIGH OF FLOW IN INCHES IN CIRCULAR SEWER 8'5 FEET IN DIAMETER
AREA IN SQUARE FEET
VELOCITY IN LINEAL FEET PER SECOND
WETTED PERIMETER IN LINEAL FEET PER SECOND

PLATE V.
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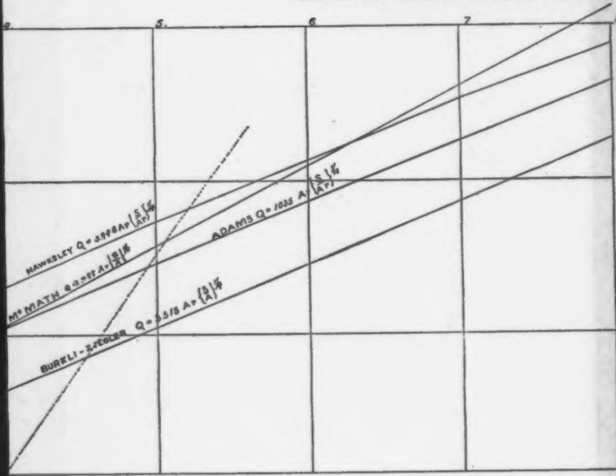
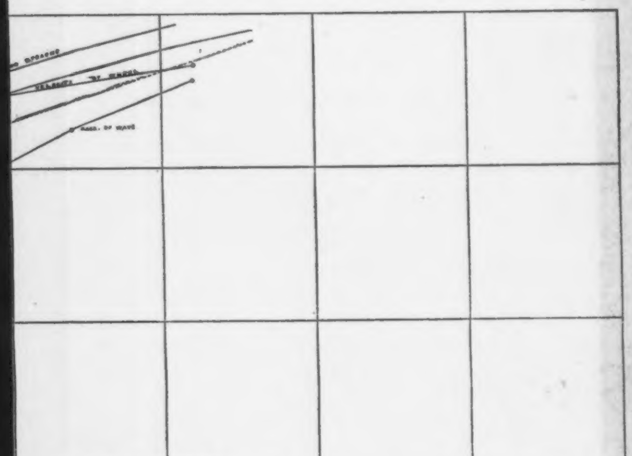




It should be borne in mind that the apparatus weighs over 150 lbs., and is a little over 16 ft. long, necessarily so to withstand the shocks to which it is subjected in so large a sewer during flood discharges, carrying boards, limbs of trees, etc., and that it is quite different from the sensitive vane wheel used in clear water.

The only practical method of rating would be to attach it to a long spar projected over the prow of a steamboat and run through a quiet lake.

There is another correction more difficult to get at and of great importance to us; that is, the location of the thread of mean velocity.

Had we our wheel correctly rated and so adjusted in a circular sewer 8½ ft. in diameter that the paddles would dip just 5 ins. below the surface, what shall we multiply our corrected recorded velocity by, to get the mean velocity of the cross-section when the sewer is one-eighth full ? And what when the sewer is half full ?

With these difficulties in mind it has been sought to show a connection between these experiments and others, by carefully running floats as recorded on Plate III. Also by diagrams given on Plate V, showing the curves of velocity given by Kutter's formula and that of Messrs. Fteley and Stearns, and a broken line connecting the maximum velocities of the perimeter of the paddle-wheel at different depths, which latter velocities were assumed to represent the mean velocities in the original paper.

If, however, we assume that either of the above formulas correctly represents the mean velocity of this sewer, a connection is made between these experiments and those of others. A crude rating of the wheel is also obtained, which indicates that the necessary corrections for slip and mean velocity to a certain extent, clearly shown, counterbalance each other in this case.

The Secretary informs me that the amount of discharge, 158 cu. ft. per second, given on page 9 of the original paper for the Hawksley-Kuichling formula, $Q = 3.946\ Ar \sqrt[4]{\frac{S}{Ar}}$ has been questioned. It was obtained as follows: $A = 2\,100$, $S = .02$, $r = .24$, the latter quantity being the greatest amount of rainfall recorded in an hour.

Perhaps a fairer application of this formula would be, that as .2 of an inch of this rain fell in 30 minutes, representing an hour rate of .4 of an inch, which, substituted for $r = .24$, gives $Q = 232$ cu. ft. per second.

If, however, we reject part of the rainfall, which this last deduction certainly does, why not take the formula just as it reads on page 25, Vol. XX, *Transactions* Am. Soc. C. E., which says, "$r =$ maximum rate of rainfall in inches per hour."

The automatic rain gauge of the U. S. Weather Bureau in this city recorded during this storm .05 of an inch in four minutes, or an

hour-rate of .75 ins., which, substituted in the preceding formula, gives $Q = 371$ cu. ft. per second.

We here note that with this value of r, the McMath-Kuichling formula $Q = 2.488\, Ar \sqrt[5]{\frac{S}{A}}$ exceeds the previous formula, as it gives $Q = 388$ cu. ft. per second, or within 2.28 cu. ft. of our gaugings.

As in this latter calculation nearly four-fifths of the total rainfall has not been considered, the novice is confounded and the old practitioner realizes the danger of empirical formulas in inexperienced hands.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

573.

(Vol. XXVIII.—January, 1893.)

BORINGS IN BROADWAY, NEW YORK.

By William Barclay Parsons, M. Am. Soc. C. E.

Read December 7th, 1892.

WITH DISCUSSION.

In order to ascertain the quality and nature of the material underlying Broadway, in the City of New York, the Rapid Transit Commission of this city undertook a system of borings in 1891 under the direction of Chief Engineer William E. Worthen, Past President of this Society, and under the immediate supervision of the writer as Principal Assistant Engineer. With the consent of the Rapid Transit Commission, the results of these borings are now laid before the Society.

In general, the system followed was to put down a test hole at every street crossing from South Ferry along Whitehall Street to Broadway, and thence to Thirty-fourth Street. These holes were sunk by the water-jet process and were carried down until rock was encountered. The method of proceeding was to select a spot where, as far as the inspector in charge could tell, the line of the hole would not encounter any pipe, subway, sewer or any other subsurface structure. One paving block would then be removed and a test would be made with a sounding rod

for 8 or 9 ft., to determine whether the location was free from obstructions. If so, a 2-in. pipe would be driven to serve as a casing. In order to drive this pipe a small portable pile-driver was used, the top of the pipe being covered with a protecting cap. The hammer, weighing 150 lbs., was directed between four light metal guides and had a fall of about 6 ft., the whole arrangement being supported on a cast-iron stand. The hammer was raised by hand power.

After two or three lengths of casing had been driven, the protecting cap was removed and a tee screwed on in place, and down the pipe was inserted a ¾-in. wash-pipe with a chisel point, in the corners of which were two small holes. Water was then forced into this wash-pipe while two men worked the pipe down by hand. The water thus discharged, washing the sand away from the foot of the wash-pipe, flowed upward between the wash-pipe and the casing carrying the sand with it. This water and sand flowed out of the side opening of the **T** at the top, and was caught in a bucket and sampled by the inspector in charge.

The samples were collected in wooden boxes 30 ins. long, 4 ins. wide in the clear, divided longitudinally into three compartments 30 ins. long, 1 in. wide, and 1 in. deep, and then subdivided across with tin partitions with lengths of 1½ ins.

The material removed by the sinking of each foot of the wash-pipe was sampled and put in one of these compartments. Some of the results obtained were quite different from what had been expected; first, rock was at a much greater depth than had been believed, being over 163 ft. down at Duane Street; secondly, the rock at Canal Street is not the deepest along the line; thirdly, the material underlying the surface at Canal Street is not muck and fine sand, but, on the contrary, consists largely of good coarse gravel, and presents an excellent material for foundations.

The annexed profile (Plate VI) shows the depth of each hole, and the stratification of the sand and gravel as met. There were 59 original borings put down, and three additional check borings at Duane, Thomas and Canal Streets. These 62 borings aggregated 4 030.98 ft., to which are to be added 87.35 ft. of borings that met obstructions at a short depth and were abandoned for another trial, making a total of 4 118.33 ft. of work done.

The total amount of time spent in doing this work was 662.25 hours

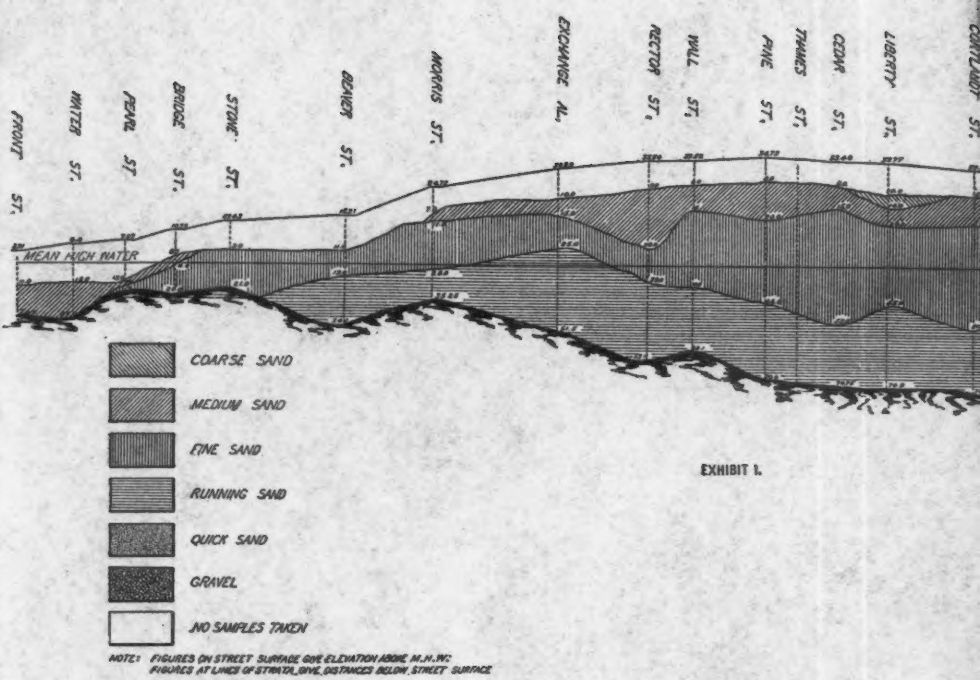
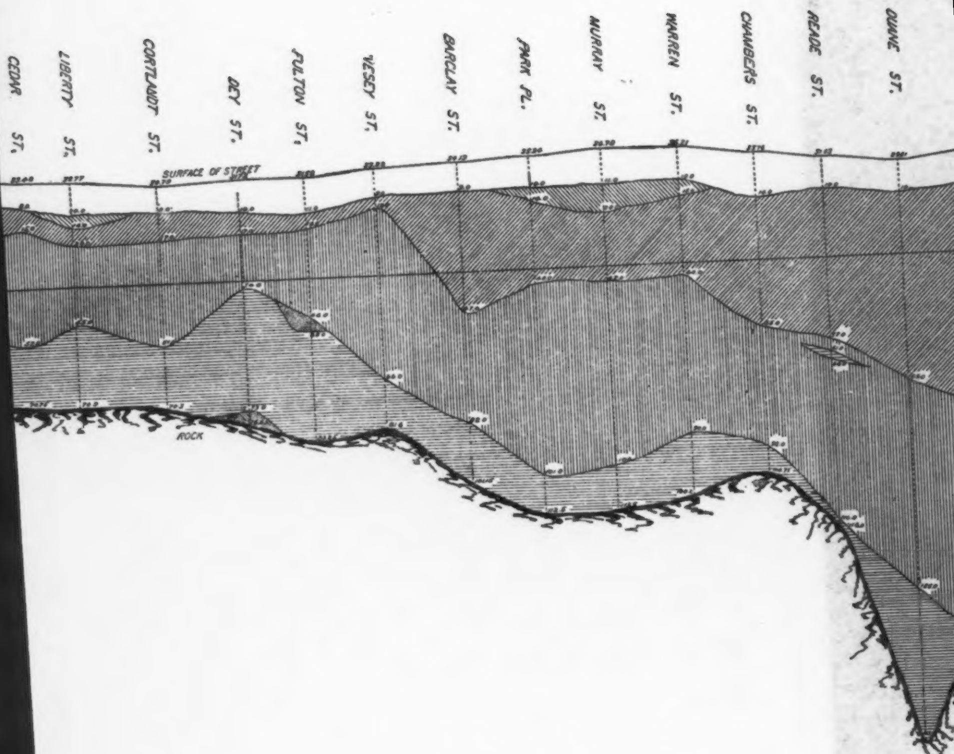
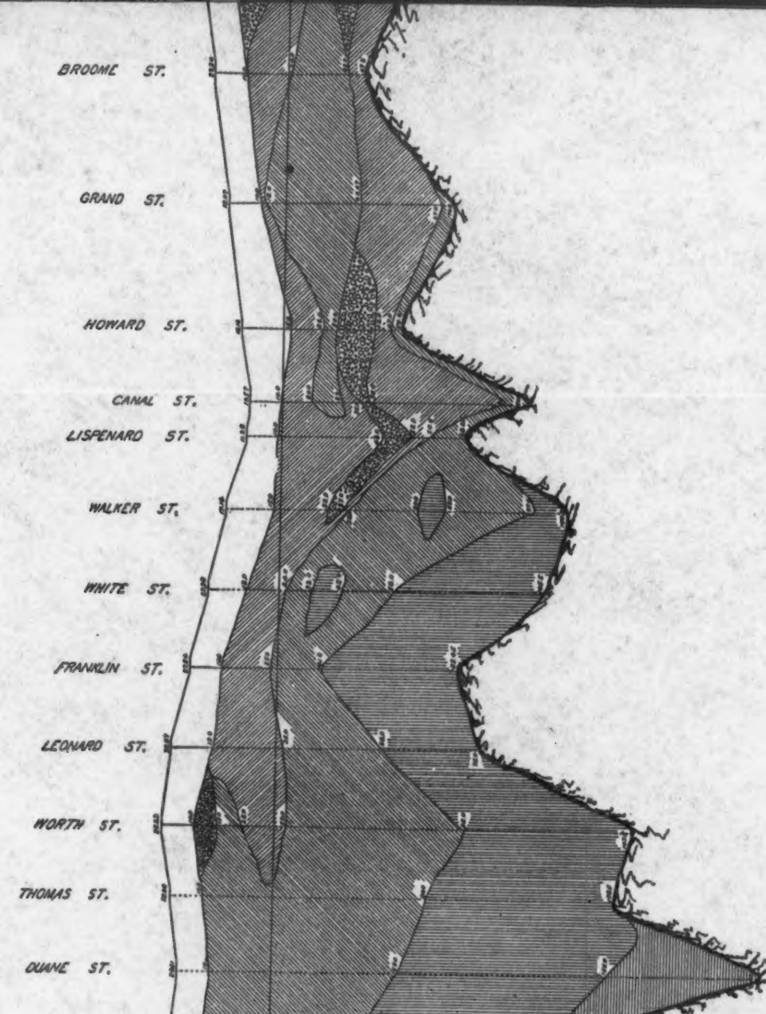

FRONT ST.
WATER ST.
PEARL ST.
BRIDGE ST.
STONE ST.
BEAVER ST.
MORRIS ST.
EXCHANGE AL.
RECTOR ST.
WALL ST.
PINE ST.
THAMES ST.
CEDAR ST.
LIBERTY ST.
CORTLANDT ST.
MEAN HIGH WATER
COARSE SAND
MEDIUM SAND
FINE SAND
RUNNING SAND
QUICK SAND
GRAVEL
NO SAMPLES TAKEN
NOTE: FIGURES ON STREET SURFACE GIVE ELEVATION ABOVE M.H.W.;
FIGURES AT LINES OF STRATA GIVE DISTANCES BELOW STREET SURFACE

EXHIBIT I.



CEDAR ST.
LIBERTY ST.
CORTLANDT ST.
DEY ST.
FULTON ST.
VESEY ST.
BARCLAY ST.
PARK PL.
MURRAY ST.
WARREN ST.
CHAMBERS ST.
READE ST.
DUANE ST.
SURFACE OF STREET
ROCK



BROOME ST.
GRAND ST.
HOWARD ST.
CANAL ST.
LISPENARD ST.
WALKER ST.
WHITE ST.
FRANKLIN ST.
LEONARD ST.
WORTH ST.
THOMAS ST.
DUANE ST.

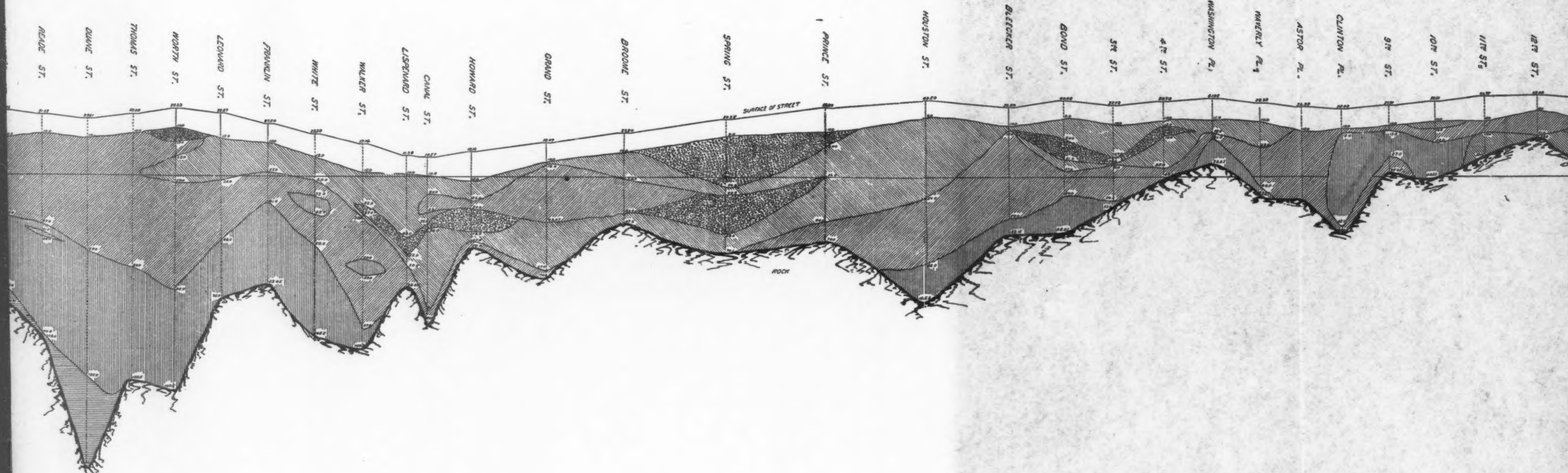
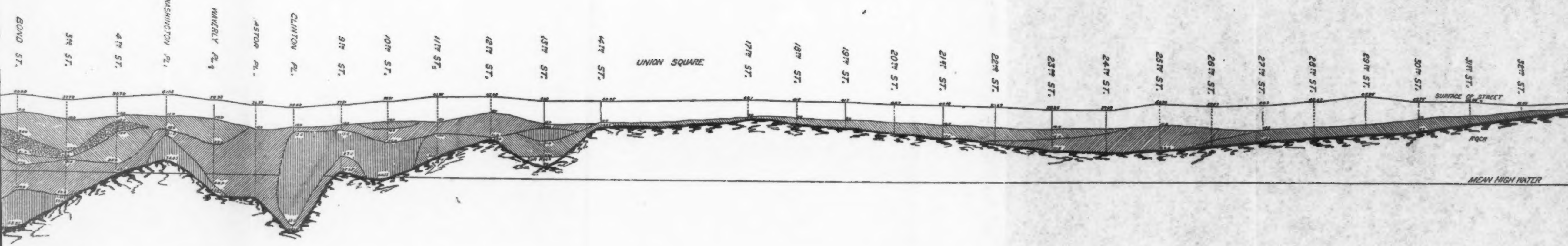

READE ST.
DUANE ST.
THOMAS ST.
WORTH ST.
LEONARD ST.
FRANKLIN ST.
WHITE ST.
WALKER ST.
LISPENARD ST.
CANAL ST.
HOWARD ST.
GRAND ST.
BROOME ST.
SPRING ST.
PRINCE ST.
HOUSTON ST.
BLEECKER ST.
BOND ST.
3RD ST.
4TH ST.
WASHINGTON PL.
WAVERLY PL.
ASTOR PL.
CLINTON PL.
9TH ST.
10TH ST.
11TH ST.
12TH ST.
SURFACE OF STREET
ROCK

PLATE VI.
TRANS. AM. SOC. CIV. ENGRS.
VOL. XXVIII, No. 573.
PARSONS ON BORINGS IN BROADWAY.



for one boring machine. Each boring averaged 65 ft., requiring 10.68 hours, or 9.65 minutes per foot of boring. As a rule, three men were employed on each machine, of which several were in use, one foreman being able to look after two or more machines. As will be seen from the profile, the lengths of individual borings varied greatly, from a minimum of 10.15 ft. at Seventeenth Street, to 163.25 ft. at Duane Street. It was not found necessary to case the holes their entire depth, the amount of casing depending upon the nature of the material. If the sand was fine, it was found that it stood without casing; whereas, if it was coarse, or especially in gravel, water from the wash-pipes would run away and would not rise. The total number of feet of casing used was 2 753.8 ft., an average of 44 ft. per hole; or about two-thirds of each boring was cased.

As was above stated, there were very great variations in this regard. At Cortlandt Street, where the hole was 70.3 ft. deep, but 20 ft. of casing were used, and at Fulton Street, but 25 ft. out of 83.25 were cased; whereas, at Leonard Street, it was found necessary to case 95 ft. out of 96.55, and at Canal Street, 85 ft. out of 87.65, and at Spring Street, 69 ft. out of 70.1.

In order to check some of the results, additional holes were put down at Duane, Thomas and Canal Streets, on the opposite side of Broadway. At Duane Street, a second hole gave a depth of 149 ft. as against 163.25, the first hole. The ground, however, was about one-half a foot lower, so that the actual difference between the two was 13.75 ft. At Thomas Street the results agreed within a quarter of a foot, and at Canal Street, within a foot.

It is believed that these borings are the most complete that have ever been made in the lower part of the Island, and will, therefore, be of value as a record.

DISCUSSION.

R. L. Harris, M. Am. Soc. C. E.—At 160 ft. depth of sounding, how did you know the difference between ledge rock and boulders ? Was more than one boring taken ? Take any of the deep borings between Houston and Duane Streets, how would it be certainly determined whether you are striking ledge rock or a large boulder when driving pipes with a jet or running down a drill rod ?

Mr. PARSONS.—It is, of course, impossible to tell whether we struck ledge rock or a boulder, or some other obstruction. I believe that the borings indicate a line of ledge rock for three reasons : first, because a profile made up from the borings indicates a surface reasonably regular, without any extraordinary or suspiciously abrupt variations ; second, in all building foundation excavations, at least along the route followed by the borings, nothing but sand and gravel is encountered down to rock ; third, check borings made at several places on the opposite side of the street from the original borings gave substantially corresponding results. Thus at Canal Street when the rod indicated a depth of 87.65 ft., I was not satisfied that rock had been reached ; not that I had any special reason to doubt it, but from the fact that I had expected to go very much deeper, as rock at Canal Street has always been popularly supposed to form a deep hole. The check boring on the opposite side of Broadway, distant about 80 ft. from the first one, gave a depth of 86.05 ft. In some of the borings along Whitehall Street, we encountered obstructions of wood, as shown by chips worked off by the chisel point of the wash-pipe. On this account in several places in that locality we had to make more than one attempt to get through the first 10 ft.

Mr. FLAGG.—Your borings were oftener than every block ?

Mr. PARSONS.—No ; the borings were made at every cross street.

Mr. HARRIS.—This was a very interesting work. I spent two or three summer nights very pleasantly in watching the operations.

There is another matter spoken of by Mr. Parsons, viz., the apparatus used for driving the casing pipes. I have had occasion to see several different kinds of machines, and there is one used at Providence, R. I., which is superior to those used in this vicinity; with the machines I have seen used about New York, time is lost in moving away the driving hammer in order to introduce the water-jet, and *vice versa*. With the Providence apparatus, the hammer slides on an extension of the casing pipe, the jet pipe entering at the top of the extension above the run of the hammer, thus saving any lateral movement of the hammer and its leaders. The Providence machine is well described and illustrated in the *Engineering Record* of date January 9th, 1892 (p. 95).

CHARLES B. BRUSH, M. Am. Soc. C. E.—That device is not unknown in this section ; the water is applied in just that way.

There is one thing that ought to be said about these borings, they do not indicate where rock is ; they indicate where rock is not. There is a distinction between those two statements. In the great majority of cases all that is necessary to know is the fact that rock does not exist down to a certain depth ; but it is impossible by this method of boring to determine that you have struck a large rock—whether it is rock or boulder. The borings are very useful because they show for a long distance that you have not encountered rock ; but the moment you encounter something you cannot tell whether it is rock or boulder.

The only apparatus that will satisfactorily determine that fact is the diamond rock drill. This, of course, is very expensive.

F. Collingwood, M. Am. Soc. C. E.—One experience I had in boring was in examining the foundation of the New York pier of the East River Bridge. I put down some 10 holes with a 6-in. pipe. When the pipe had penetrated to within a short distance of the rock (I could not tell the exact distance, but it was very close) there was a decided change in the material. We invariably found a collection of very hard pebbles, and in almost every one of the holes I found it impossible to drive the pipe further. We would break the heavy steel shoe or bend the pipe; but could not get it down to rock. I wish to say also that in that small space, 102 x 172 ft., the rock was met at depths varying as much as 18 ft. It seems that the gneiss rock of that vicinity, where it was covered by the drift, was left with sharp, jagged projections, and was very irregular throughout.

Mr. Harris.—May I ask one more question ? In borings made as described, is it probable that you get a fair sample, or do you get a sample finer than the actual material at the depth ; that is, are not the finer materials forced up, and do not the coarser ones settle down ?

Mr. Parsons.—I feel pretty confident that our results were just the reverse, namely, that the samples were, if anything, coarser than the actual condition of the sand. Thus, at Canal Street, where we encountered gravel beds, it was found that coarse stones had apparently no trouble in coming up, showing that the coarse material rose without difficulty. Of the fine material, on the contrary, I think the larger amount was lost, owing to the difficulty of catching it in buckets, where a very large portion of the very fine sand would not have a chance to settle, but would be washed away with the overflowing water, so that the sediment on the bottom of the bucket was, I think, rather coarser than the actual sand.

As to what Mr. Brush has said, it is a fact that all we have proved is "where rock is not." But still I think that we can argue pretty safely from the inferences, as explained in my answer to Mr. Harris, that we have also proved where rock is.

Charles Warren Hunt, M. Am. Soc. C. E.—I would like to ask Mr. Parsons if there were any borings in which it was necessary to drive the casing all the way down to the rock, or whether in all cases the material overlying the rock could be worked through with the drill and water-jet alone. I also would ask if the sizes of pipe used were fixed as being the best for the purpose or for other reasons. I have made many similar borings and have found 1½-in. and ½-in. pipe very convenient and amply large for the purpose.

Mr. Parsons.—The pressure of water required to put down the wash-pipe was not great. At Canal Street, Howard Street, and at one or two other low level points, we found that the ordinary hydrant

pressure was quite sufficient. On higher ground, an ordinary hand-pump worked by one man, taking suction from a barrel, gave sufficient head. As to the necessity of driving the casing, I have already explained in the body of my paper that it depended entirely upon the coarseness of the material. If the sand was fine, we found it necessary to drive the casing but a short distance. In many cases, the last 40 or 50 ft. were not cased at all. Thus, at Duane Street, the casing stopped 58.25 ft. above the rock. On the other hand, where the material next to the rock was coarse, it was necessary to drive the casing away down, which state of affairs existed in the neighborhood of Canal, Grand, Broome and Spring Streets, and Washington Place.

The only consideration that governed the sizes of the pipe used was that they were the sizes that the contractor who did the work had in stock. With the possible exception of Canal Street, where there was one layer of gravel that was quite coarse, I think that 1¼-in. casing with ½-in. wash-pipe, as suggested by Mr. Hunt, would have been quite as effective and more convenient to handle.

Mr. Brush.—The force with which gravel is thrown up is often great. I made some borings at Jamestown some time ago. The pipe was driven down through the clay, and as the core was excavated from the tube the force of the water was so great that it drove all the material out of the tube and threw up stones 4 to 6 ins. in diameter, and threw them with such velocity as to endanger the safety of the men. The water arose in the pipe perhaps 50 ft., but the velocity and noise were so great as to be heard for a long distance.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

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574.
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CONSTRUCTION OF THE POWER-HOUSE OF THE ROCHESTER POWER COMPANY, ADJACENT TO GENESEE FALLS, ROCHESTER, N. Y.*

By Robert Cartwright, M. Am. Soc. C. E.

Read February 1st, 1893.

The development of the water-power of the Genesee River at Rochester, N. Y., has always been an important consideration to those interested in the city's manufacturing industries. Draining an extent of territory embracing about 2 500 square miles and extending entirely across the State from north to south into the State of Pennsylvania, the river at times becomes a flood that pours over the Genesee Falls (immediately in the city) in a volume 293 ft. in width and from 5 to 6 ft. in depth, with a perpendicular fall of about 90 ft. From this fall the water follows the ravine a distance of about 1 mile and then by two lower falls it reaches the level of Lake Ontario. The total fall of the water within the city limits is 257 ft. By a series of dams the water is used over four times before it reaches lake level. Its power is utilized for many manufacturing purposes, but especially has it been used for many years in producing the finest grades of flour.

* Discussion on this paper received before April 1st, 1893, will be published in a subsequent number.

Although many of its mills remain as they were generations ago, their machinery has undergone successive changes for the better and they are now fully up to modern improvements and utilize the water much beyond the practice of days gone by.

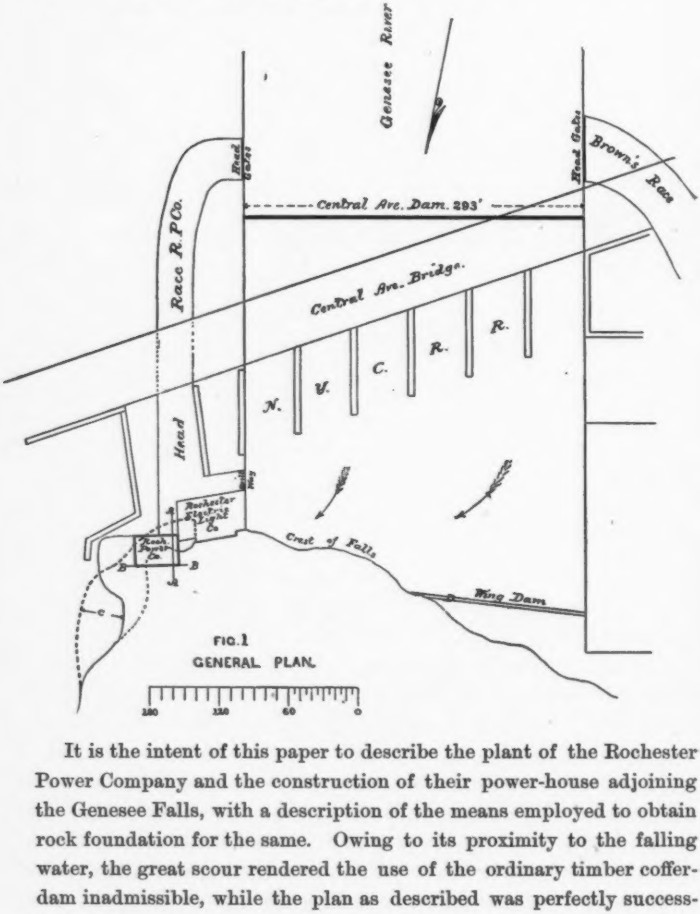

FIG. 1
GENERAL PLAN.

It is the intent of this paper to describe the plant of the Rochester Power Company and the construction of their power-house adjoining the Genesee Falls, with a description of the means employed to obtain rock foundation for the same. Owing to its proximity to the falling water, the great scour rendered the use of the ordinary timber coffer-dam inadmissible, while the plan as described was perfectly successful and comparatively inexpensive.

By reference to the accompanying plates, the position of the power-house in its relation to the Falls will be readily understood.

PLATE VII.
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CARTWRIGHT ON POWER-HOUSE AT ROCHESTER, N. Y.

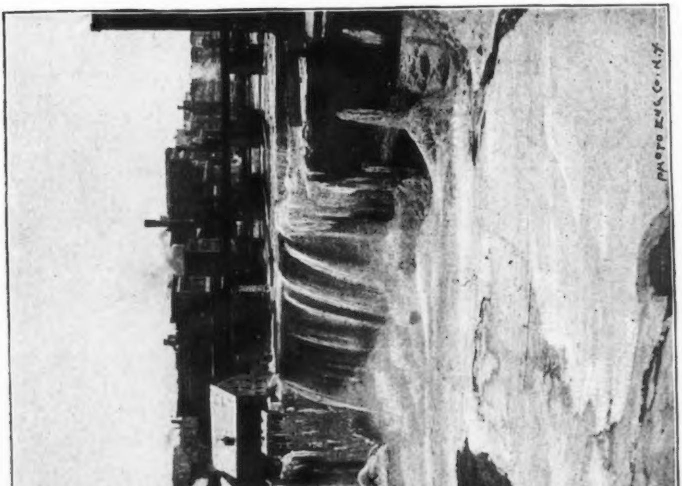


Fig. 1 is a general plan of the locality on a scale of 60 ft. to the inch.

Fig. 2 is a sectional elevation on line *AA*, showing slope of the rock below water level.

Fig. 3 is a front elevation on line *BB*.

Fig. 4 is a plan of the building at the wheel floor.

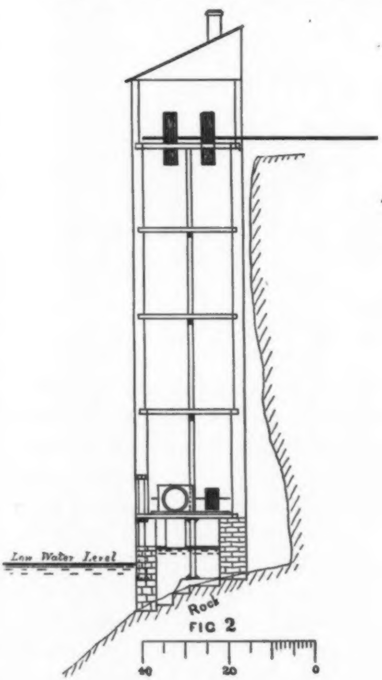


FIG 2

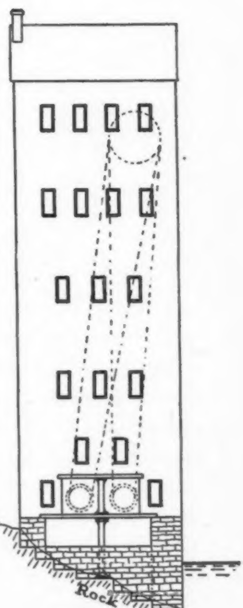


FIG. 3

Plate VII is a photograph of the Falls and completed building in December, 1891.

Plate VIII is a photograph of the Falls and completed building in March, 1892.

As shown in Fig. 1 a wing dam *D* at the crest of the Falls tends to divert the water in the direction as shown by the arrows.

The main dam is located about 300 ft. from the brink of the Falls, the water being drawn on the west side to supply Brown's Race, with

a long list of mills and factories obtaining power from it. On the east side the water only supplies power to the Rochester Electric Light Company, about 1 400 H. P., and to the Rochester Power Company about 1 200 H. P.

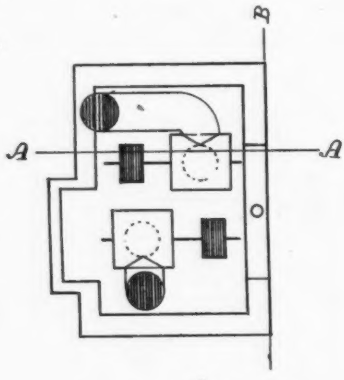
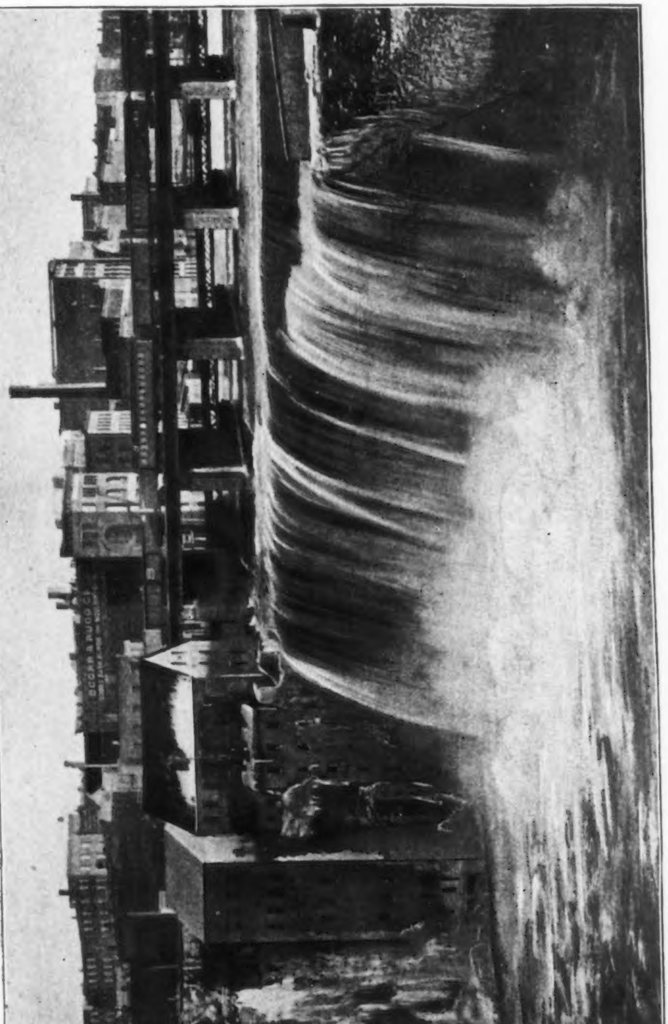


FIG. 4

In the spring of 1890 the interests of the Rochester Hydraulic Company on the east side of the river were acquired by some Boston capitalists. The property embraced a long line of buildings parallel with the river and covering a distance of about one-quarter of a mile, occupied by manufacturers engaged in various kinds of business, all requiring power. The equipment was composed of one 36-in. wheel operated under a head of about 40 ft. and discharging its tail water to a 36-in. wheel under 35-ft. head. Owing to the crude construction of the whole affair, only about 300 H. P. was realized from the plant. Immediately on coming into possession of the plant the work of improvement was commenced. As the power must necessarily be constant to keep the various factories moving, a 300-H. P. Greene engine, built by the Providence Steam Engine Company, of Providence, R. I., was installed and put in operation in August, 1890, and thereupon the water-wheels and the dilapidated building containing them were removed.

By reference to Fig. 1, the proposed power-house is represented by the heavy line parallelogram. The heavy dotted line shows the undercut of the rock at the surface of the water in the pool below the Falls.

PLATE VIII.
TRANS. AM. SOC. CIV. ENGRS.
VOL. XXVIII, No. 574.
CARTWRIGHT ON POWER-HOUSE AT ROCHESTER, N. Y.



The light dotted line shows the rock at the crest level of the Falls at the time of commencing the work. The continuous line shows the present rock at the level of the Falls. As it would not do to endanger the new building by leaving any overhang that might fall against it, the rock was removed as shown at top and sloped down to the bottom, with a batter of 1½ ft. in 10.

The work of removal was carried on day and night, until early in November, 1890, when the freezing of the spray from the Falls caused such an accumulation of ice that it was impossible to maintain a foothold, and the work was suspended until late in March, 1891, when it resumed, and by the 1st November, 1891, all was completed and in satisfactory operation, since which time the water-power has been constantly in use. Owing to drought in some summer seasons very little water is available in the Genesee, and the steam engine is designed to supply power on such occasions.

The hydraulic plant was designed and furnished by the Robert Poole & Son Co., of Baltimore, Md., and consists of two double Leffel wheels 26½ ins. in diameter, each supplied by a 5-ft. diameter flume; under an effective head of 87 ft., with a volume of 6 250 cu. ft. of water per minute, they develop 600 H. P. each. The wheels proper are made of phosphor bronze with buckets of tinned Otis steel. From a 5-ft. rope-wheel on the wheel shaft, power is transmitted to a 12-ft. rope-wheel on the line shaft 90 ft. above, through the medium of 16 1⅜-in. Manila ropes. Said ropes are endless and are adjusted by a single strand tightener wheel in a frame, that has a vertical adjustment of some 30 ft. to allow for stretch or contraction of the ropes. Every precaution has been taken to maintain a constant and uninterrupted power. Each double wheel has its own flume or supply pipe, head gate and governor, and by an arrangement of clutch couplings the wheels are used alternately, thus giving each about the same amount of wear. The rope speed is the greatest that the writer knows of, being 7 540 ft. per minute. Since being started in November, 1891, the whole plant has run daily, and not a moment's delay has been experienced in its operation, the whole installation being as perfect as when it was started. As a specimen of workmanship and in its performance, it sustains the well-known reputation of its builders for first-class work.

As stated previously, the Falls have a vertical drop of about 90 ft. from the crest to the level of the water in the pool below. The rock at

top overhangs the bottom some 15 to 20 ft., while the depth of the water in the pool below is some 40 to 50 ft. The rock strata is a shale that is comparatively easily disintegrated by the action of the weather. In Fig. 1, as will be seen at point *C*, the rock now overhangs the bottom some 41 ft.

At the northwest corner of the building the water was 10.7 ft. deep at lowest stage of the river, and at a point 13 ft. northward the water was 22 ft. deep, showing the slope of the bottom to be about 45°. So treacherous is the river that it is frequently raised to a half flood in 24 hours. On one occasion, while prosecuting the work the water rose in the night and carried off some 7 000 ft. B. M. of lumber, besides all the tools, and yet no rain had fallen at Rochester.

Owing to the wing dam shown at *D*, the current is diverted to the east side of the Falls in the direction of the arrows, thus bringing the location of the power building more directly under the action of the falling water and tending to scour out the bottom. The use of timber coffer-dams was not to be considered for a moment, so close to such a body of water falling 90 ft. The large mass of overhanging rock that must necessarily be removed to admit of the building was the best means of offering resistance in the shape of a heavy rock fill. Accordingly the rock was shot off and dropped into the pool below, forming a plateau some 12 to 15 ft. above the water and extending out beyond the site of the building, to admit of placing steam boiler and centrifugal pumps on it. The debris was first removed on the south and east sides, where the rock was soonest reached. Level benches were then dressed on the rock and a heavy footing course of stone, laid in American Portland cement mortar, built to proper dimensions thereon, and the walls carried to high-water level. The mass of stone outside the line of the north and west walls was removed for a distance of 8 or 10 ft., and as the water was encountered a flour sack filled three-quarters full of dry cement mortar was forced into the space caused by the removal of a stone. This was trodden into place, so as to fill the irregularities of the openings, sometimes a half dozen sacks being used to stop the inflow from the removal of a single stone. Pumps with 4 and 6-in. suction pipes, admitting of a ready vertical adjustment, were so arranged that as the water was lowered and an inflow disclosed, the placing of a cement bag or two would overcome the difficulty. The cement mortar would set without the cement being washed out of the mortar, as would have

been the case if not enclosed in bags. By the judicious removal of the loose stone, which was accomplished with a derrick, the bottom was readily uncovered and as it was persistently followed up by leveling the rock and getting down a footing stone, every stone laid was so much water cut off. The footing course was composed of stones from 12 to 14 ins. thick and not less than 4 ft. square, bedded in cement mortar on the rock. Figures Nos. 2 and 3 show the plan of benching. Sometimes a stone in removal would start several others and the rush of water would be more than the pumps would remove. By sinking the bags into the location and treading them down, we could generally overcome the leak. Sometimes we would pile on three or four thicknesses of them, to hold back the water. The closing up of the northwest corner under a head of 10.7 ft. of water was successfully accomplished, though extremely low water existed for the two nights and three days that the closing up occupied. The work was accomplished at less cost than any constructed coffer-dam would have been, even admitting that a timber coffer-dam could have withstood the scour and agitation of the water. Stones of 1 to 2 cu. yds. content were carried 200 ft. down the stream and lodged in shoal water where they are now to be seen at low water.

As soon as the foundation walls were above high water the engines, pumps, etc., were removed and the first freshet carried off the material where they had been located. Every succeeding flood has carried away more or less of the tons of rock that formed the temporary coffer-dam and the water is now washing against the masonry at bottom. Plate VII was taken in the fall of 1891 shortly after the wheels were started, and shows much of the rock-fill still remaining at the northwest corner of building. Plate VIII was taken in the spring of 1892, and, as will be seen, the floods had carried off all the fill.

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(Vol. XXVIII.—January, 1893.)

THE EFFECT OF TUBERCULATION ON THE DELIVERY OF A 48-IN. WATER MAIN.*

By JAMES DUANE, M. Am. Soc. C. E.

READ FEBRUARY 1ST, 1893.

Authentic data as to the effect of tuberculation on the discharging capacity of water mains are comparatively rare, and when obtainable is correspondingly valuable. Therefore, as the writer has been favored with an unusually good opportunity for observing the loss of head due to this cause in a large water main, and the comparison of this loss with that in a perfectly clean coated new main discharging under identically the same conditions, it is believed that a description of these observations may be of interest to such of our members as are connected with hydraulic works.

In 1880–81 the writer laid a 48-in. main in Tenth Avenue and Eighty-fifth Street for the purpose of diverting a portion of the flow of the aqueduct into the Old Receiving Reservoir in Central Park, which, since the abandonment in 1879 of the 6-ft. pipes laid by the Old Aqueduct Department in 1867, had been without any direct supply. This

* Discussion on this paper received before April 1st, 1893, will be published in a subsequent number.

pipe was connected with the old masonry aqueduct in Central Park and Eighty-fifth Street, leading to the Old Reservoir, and also with the most westerly of the six 48-in. aqueduct mains on Tenth Avenue and Ninety-third Street, from which it drew its supply.

As these aqueduct mains form an important link in the aqueduct system, a brief description may not be out of place. To quote from the Department Report for 1872:

"The aqueduct between Ninety-third and One hundred and thirteenth Streets was located with special regard to its economical construction and without any special reference to what the future grades of the streets and avenues might be. The opening of the Central Park made it necessary to establish grades between Ninety-second and One hundred and thirteenth Streets on a much lower level than the existing Croton Aqueduct would admit of, in consequence of which it now intersects that part of the city, interrupting communication from East to West. In 1870 a law was enacted by the Legislature directing this Department to remove that portion of the Aqueduct and to replace it by one below the established grades of streets, or by iron pipes. It was decided by the Department that the supply could be more safely conveyed through iron pipes than through an aqueduct of masonry under a heavy pressure of water, and also that the supply would be more secure if conveyed through a number of lines of pipe than if all depended on one line. It was therefore concluded to lay a sufficient number of 4-ft. pipes to carry to the distributing reservoirs the full quantity of water that the aqueduct can supply."

In fulfillment of this decision six parallel lines of 48-in. pipe were laid between the years 1871–74. The arrangement of the system, the masonry aqueduct, mains, gate-houses, etc., is shown on the general plan, Plate IX. In order to avoid confusion, but one of the six mains is shown. The elevations given are those of the inner bottoms of pipes or aqueduct above city datum—mean high water. In order to conform to the street grades at One hundred and thirteenth Street, the Aqueduct at this point is depressed 3.15 ft. below the hydraulic grade line, but it rises sharply until the two again coincide at a point about 150 ft. north. The sections of the gate-houses clearly show the method of connecting the mains with the masonry structure, and seem to need no special explanation. As will be seen, each pipe is controlled by two rectangular gates, 2½ x 5 ft., worked from the upper floor of the gate-house in the usual manner. It may be added that these gates worked very nicely and closed tight, there being no appreciable leakage.

Bench marks were established at *A*, *C* and *D*, on the edges of the masonry manholes over the mouths of the pipes at convenient points for measuring down to the surface of the water, thus determining its elevation above datum in each case. The benches in all cases were checked by an independent line of levels run by a second observer. The measurements from these benches to water surfaces were made simultaneously at all points with an ordinary graduated rod, and it is believed that the extreme errors, in observed loss of head, did not exceed .02 or .03 of a foot.

The aqueduct mains were laid true to line and grade, on good foundations, curves were accurately formed to 50-ft. radii, and the junctions of the ends of the pipe lines with masonry structure were formed by converging mouthpieces, as shown on the plan. In short, all the requirements of the best engineering practice in pipe laying had been complied with, except in one very important respect. These castings had been laid just as they came from the mould without the coating of coal-tar varnish, which is now universally applied.

Why such a marked departure from general usage has been made has never been satisfactorily explained, and a diligent search through the reports of that time fails to throw any light on the subject. In making the connection already mentioned between the old and new mains at Tenth Avenue and Ninety-third Street, it became necessary to cut out the old main at that point, and it was found to be tuberculated to a surprising extent, even though it was uncoated, considering that it had been in use but seven years. In fact, the interior surface was so very bad that the desirability of observing the loss of head due to such a condition at once suggested itself. The description of the interior surface of a pipe as badly tuberculated, very rough, etc., is so very vague and unsatisfactory that a more definite description of the actual condition of the main under discussion will be attempted, though it must be conceded that an accurate description is very difficult, if not impossible, to make. Therefore, what follows should be taken as a rough approximation only, but better than no description at all. All the tubercles were of the same general shape—roughly formed frusta of cones, with base of from two to three times their altitude, and with roughly flattened tops looking not unlike the mud wasps' nests one often sees plastered in the angles of old country buildings. As a general statement the largest of these tubercles occurred on the bottom

of the pipe and decreased in size with some show of uniformity till they attained a minimum at the top. They studded the interior surface at irregular intervals, nearly covering it, however. The largest observed tubercles were from 2 to 3 in. diameter of base, and 1 in. high, and the smallest were about one-fourth of these dimensions. Subsequent examination of another one of the six mains showed precisely the same state of things, so it is but fair to assume that all were similarly affected.

Passing now to the observations on the flow through these pipes; as the aqueduct was at this time discharging a known quantity of water with great uniformity, day after day, and as these mains took it all, with trifling exceptions, hereafter noted, it is believed that the value of the coefficient " C" in the well-known formula $V = C\sqrt{RI}$, has been determined with considerable accuracy for the case in hand.

In common with many hydraulic engineers whose sympathies are rather with the practical than the theoretical, the writer has a decided preference for the simple formulas of flow of the Chezy type over the more complex, and he believes not more accurate, ones of Kutter, Weisbach, *et al.* For the degree of accuracy obtainable from any formula is dependent on the ability of the user to make a more or less (usually less) scientific guess at the value of a modifying coefficient appropriate to each specific case.

Regarding the flow through the aqueduct proper, a daily record is kept at Sing Sing of the depth of water flowing through the aqueduct at that point and the discharge corresponding to different depths has been determined with considerable accuracy. For ordinary depths of water the equation $V = 135 \sqrt{R\ I}$ gives satisfactory average results. In which as usual

$V =$ velocity in feet per second.

$R =$ Hydraulic mean radius.

$I =$ Sine of angle of inclination.

At the time in question the depth of 7 ft. 4 in. was maintained with great regularity day in and day out. For this depth we have the following data.

$R = 2.38$ ft.; $I = .00021$; area $= 49.24$ sq. ft., which corresponds to a flow of 96 000 000 galls. per day. This entire volume, with the following exceptions, was discharged through the 48-in. aqueduct mains under discussion. At Fordham the aqueduct was tapped by a 20-in.

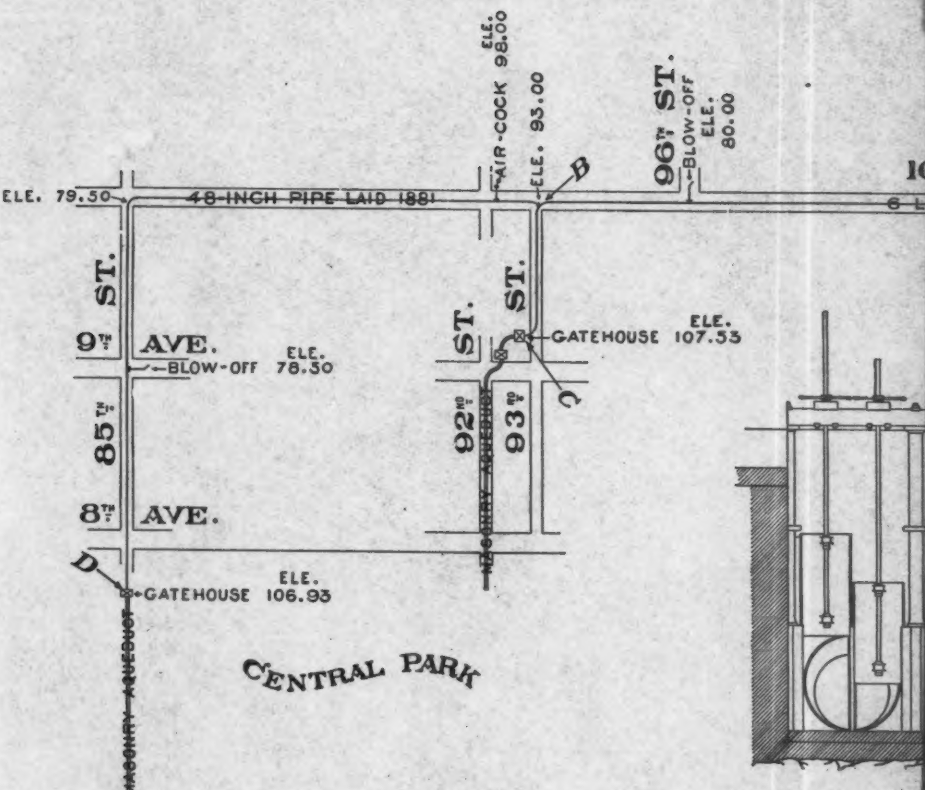
main, which at that time supplied the "Annexed District," the consumption being about 1 800 000 galls. per day.

Another 20-in. branch was taken off the aqueduct mains at Manhattan Street for the supply of the western portion of Harlem, then but a sparsely populated village, consuming but 1 500 000 galls. per day. In addition to these a 30-in. main from the aqueduct supplied the High Service pumping station at High Bridge, but the demand upon this was so slight in 1881 that the pumps were run only eight hours per day, and observations on the Tenth Avenue mains were taken when there was no draft at this point, so that the deductions to be made from the total flow, including all probable leakage, would be about 3 500 000 galls., leaving a net total flow through the five Tenth Avenue mains then in use of 92 500 000 galls. per day, or 18 500 000 galls. each.

This for the observed loss of head of 3.39 ft. in a length of 5 992 ft. gives to "C" the extremely low value of 96, about 30% less than that assigned to it in ordinary modern practice.

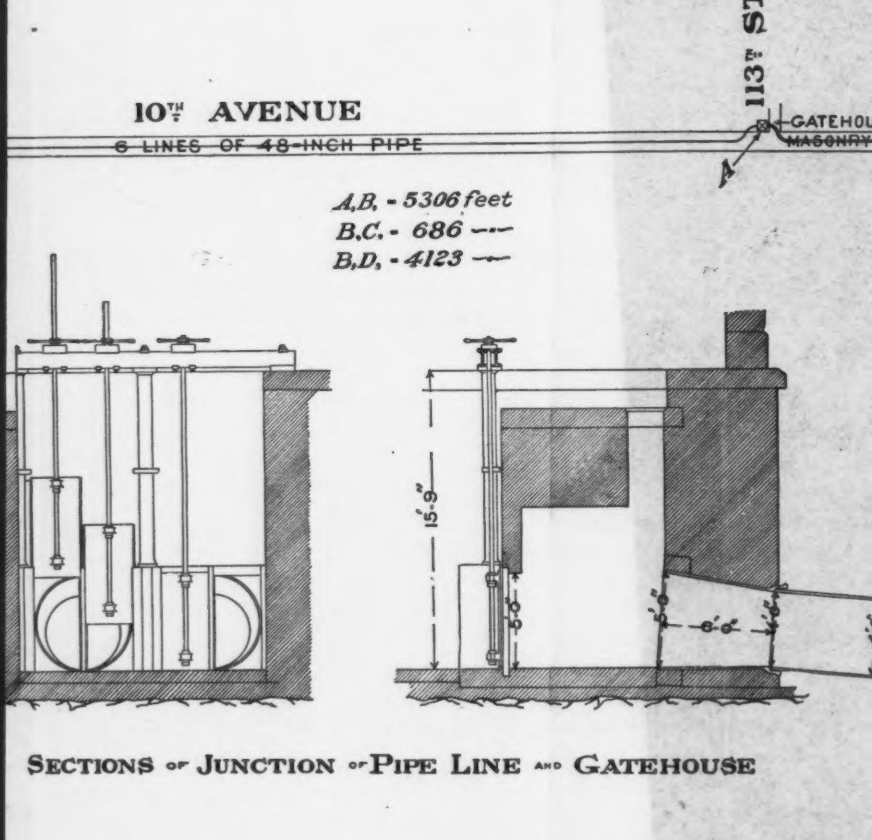
After the connection had been made between the old and new 48-in. lines at Ninety-third Street and Tenth Avenue a capital opportunity was offered for comparing the loss of head in the tuberculated pipe with that in the clean tar-coated one. As will be seen by the plan, the gates on the westerly line in Ninety-third Street Gate House being left closed, the old westerly main and the new one connected with it formed one continuous pipe line from the One hundred and thirteenth Street Gate House to the masonry aqueduct in Central Park at Eighty-fifth Street 9 429 ft. long, of which 5 306 ft. were tuberculated and 4 123 ft. clean, while the branch 686 ft. long to the Ninety-third Street Gate House acted as a very efficient piezometer between the two systems. The observed loss of head in the first section was 1.86 ft. while that in the second was but 0.74 ft. In other words, the value of I in the first section was .00035, as against .00018 in the second—nearly double.

With the data thus obtained and employing the value of "C" already deduced at 96, we obtain a flow through the first section of 14 500 000 galls. per day, all of which, of course, with the exception of any leakage (which in this case is believed to have been practically inappreciable), was discharged through the clean pipe also. Employing this discharge for the new main we obtain for "C" the value 134, which accords excellently with the generally accepted value under similar con-


ELE. 79.50
48-INCH PIPE LAID 1881
AIR-COCK
ELE. 98.00
ELE. 93.00
B
96TH ST.
BLOW-OFF
ELE.
80.00
ST.
9TH AVE.
BLOW-OFF
ELE.
78.50
85TH
8TH AVE.
D
GATEHOUSE
ELE.
106.93
MASONRY AQUEDUCT
CENTRAL PARK
ST.
ST.
92ND
93RD
GATEHOUSE
ELE.
107.53
C

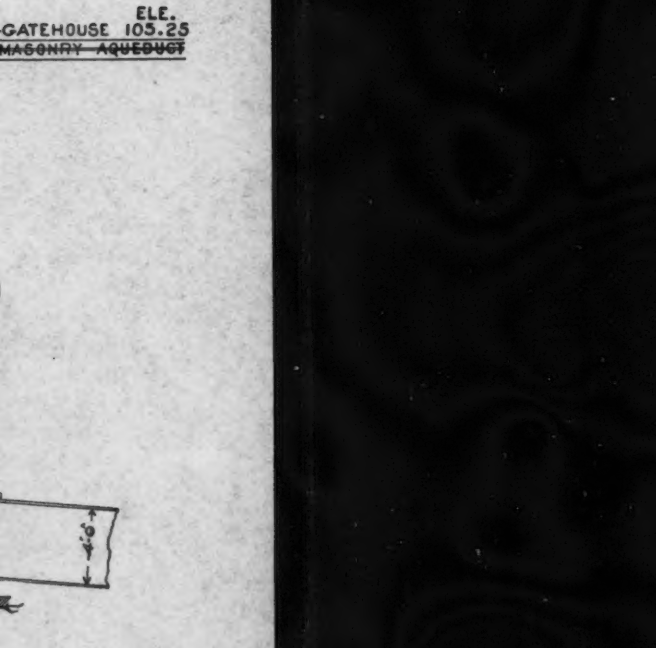
SECTIONS

PLATE IX.
TRANS. AM. SOC. CIV. EN
VOL. XXVIII, No. 575
DUANE ON TUBERCULATION IN A
MAIN.



SECTIONS OF JUNCTION OF PIPE LINE AND GATEHOUSE

ATE IX.
OC. CIV. ENGRS.
III, No. 575.
ATION IN A 48-IN. WATER
AIN.



ditions. Now, whatever errors may have been made in the foregoing estimates of volumes discharged by the different pipes, and they are believed to have been within 1 or 2% at the outside, the comparison of the loss of head in the two kinds of pipe is believed to be unimpeachable and therefore important.

About two years ago an examination of the interior of the new main in Eighty-fifth Street was made and it was found to be in perfect condition, free from tuberculation or fouling of any kind, and even the inspector's marks in white paint being still plainly legible.

Last fall, while the new aqueduct was shut off and the city again supplied through the old one, another observation was made on the flow through these mains, which showed substantially the same coefficient as 11 years ago, thus confirming the impression left by the inspection of the interior of the Eighty-fifth Street main in 1890.

It is believed from what has gone before that the following deductions may fairly be drawn :

First.—An uncoated main conveying water of the general chemical composition of the Croton will become badly tuberculated in seven years, or probably much less.

Second.—That having reached a certain stage no further deterioration takes place.

Third.—That in a 48-in. main the discharging capacity is reduced about 30%; or, to put it another way, tar coating at present prices is worth about $20 000 per mile.

Fourth.—That a properly applied tar coating is an absolute protection against tuberculation, a 48-in. main after 11 years' service showing as high a coefficient as when first brought into use.

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(Vol. XXVIII.—January, 1893.)

THE TRANSITION CURVE.—DISCUSSION ON PAPERS NOS. 528 AND 536.*

By CONWAY R. HOWARD, Esq., and ARTHUR N. TALBOT, M. Am. Soc. C. E.

CONWAY R. HOWARD, Esq.—In a paper read before the American Society of Civil Engineers in May, 1892, Professor Cain gives his views of the "exact solution" of the problem of the transition curve, basing it upon the "approximate" considerations of Mr. A. M. Wellington and myself. As in so doing he has followed more or less closely my plan and notation, some of the original approximations will be compared with their changed conditions in the "exact solution."

With regard to the angles: In the "approximate" solution there is a difference of 9" between the computation and the record of the deflection angle between the tangent at 0 and the long chord thence to station 12. These 9"—and lesser differences beginning with 1" at station 8—were

* "The Transition Curve whose Curvature varies directly as its Length from the P. C. or point where it connects with the Tangent," by Wm. Cain, M. Am. Soc. C. E., Vol. XXVI, p. 473. "A Simple Method of Running in a Transition Curve," by John F. Ward, M. Am. Soc. C. E., Vol. XXVII, p. 18.

included in the table, so that it should read to whole minutes; and the ordinates X and Y corresponding to the deflection angles and 100-ft. chords of the transition curve of the general table were then computed by summation of seven-figure natural sines and cosines of the angles of inclination, $2'$, $14'$, $38'$, $1^\circ\ 04'$, $2^\circ\ 02'$, etc., of the consecutive chords, which with decimal point moved two places to the right, that is, multiplied by 100, gave the required product to 5 decimals. The ordinates X and Y therefore are readily checked by simple addition, as are the angles by second differences. The differences between the angles and ordinates X and Y of the "approximate" solution and of Professor Cain's are too small to be of any practical importance.

A greater difference between the results of the "approximate" and the "exact solution" is shown in the lines Q and F of the table accompanying the former, which gives at station 12, $Q = 60.302$ and $F = .25105$, for which Professor Cain gives $Q = 60.180$ and $F = .25056$. Station 12 is selected for comparison because the differences there are greatest, diminishing to 0 at about station 6.

Professor Cain gives as part of the "exact solution," the formulas—

$$Q = qD^\circ = 0.2\ NX - R_1\ (1 - \cos.\ \alpha) \quad \text{.....................} \quad (21)$$

in which $R_1 = 5729.65$

$$\text{and } F = \frac{q\ D^\circ}{0.2\ N\ X} = \frac{Q}{0.2\ NX} \quad \text{...............................} \quad (22)$$

from which two formulas the values of Q and F given in his table were computed.

Questioning the merits of (21) as a general formula, and taking one step backward, his solution gives—

$$q = \frac{0.2\ NX}{D^\circ} - \frac{R_1\ (1 - \cos.\ \alpha)}{D^\circ}$$

or, otherwise expressed—

$$q = \frac{0.2\ NX}{D^\circ} - \frac{5729.65}{D^\circ} \text{ versed sine } \alpha.$$

The expression $\frac{5729.65}{D^\circ}$ except when $D^\circ = 1$ is an approximate value of the radius corresponding to D°, and as values of q are dependent, not upon the degree of curve, but upon its actual radius, it follows that the above value of $Q = qD^\circ$ is simply an approximation, except when $Q = q$ and $D^\circ = 1$.

If R represent the radius of the circular curve connecting at any station N of a 100-ft. chord transition curve, and X the corresponding

ordinate, and r and x the similar radius and ordinate for a transition curve of chord length differing from 100 ft., then :

$$R : r : : X : x, \text{ whence}$$

$$x = r\frac{X}{R} \text{ and } r = x\frac{R}{X} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (a)$$

Also

$$x - r \text{ versed sine } \alpha = q$$

and substituting above value of x

$$r\left(\frac{X}{R} - \text{versed sine } \alpha\right) = q \ldots\ldots\ldots\ldots\ldots (b)$$

When $N = 12$. $q = .0105\, r$.

Values of q obtained by this formula and from the values of Q before given, are :

D°	$q = \frac{60.180}{D^\circ}$	$q = .0105\, r$	$q = \frac{60.302}{D^\circ}$
5°	12.036	12.036	12.060
10°	6.018	6.024	6.030
15°	4.012	4.022	4.020
20°	3.009	3.023	3.015

Comparison of these figures shows that when $D^\circ = 5$, when more than six or eight stations of the transition curve are not likely to be used, Professor Cain's figures are nearer correct—that is to say, figures derived from Professor Cain's value of Q; when $D^\circ = 10$ the error is about the same by both values of Q; and when D° is over 10° the Q of the "approximate" solution gives the values of q more nearly than the Q of the "exact solution."

The fact is that both of the quantities $Q = q\, D^\circ$ and $F = \frac{q}{x}$ were called into service by me as convenient short-cuts for reaching the value of the connecting D° with the least amount of calculation in the field; and the relation of Q and F is such that Professor Cain's values and mine give practically the same values of D°. Thus with $x = 50$ and $N = 12$,

$$\text{when } F\, x = q \text{ and } \frac{Q}{q} = D^\circ$$

Professor Cain's figures:

$$.25056 \times 50 = 12.528 \text{ and } \frac{60.180}{12.528} = 4^\circ.8036$$

my figures:

$$.25105 \times 50 = 12.5525 \text{ and } \frac{60.302}{12.5525} = 4^\circ.8039$$

With $x = 10$,

Professor Cain:

$$.25056 \times 10 = 2.5056 \text{ and } \frac{60.180}{2.5056} = 24^\circ.0182$$

my figures:

$$.25105 \times 10 = 2.5105 \text{ and } \frac{60.302}{2.5105} = 24^\circ.0199$$

When q, as used by me, is not in combination with F and Q, its value is required to the nearest $\frac{1}{10}$ only.

The correct values of D° and q for connecting curves at any station can readily be obtained independently of Q or F by using formulas (a) and (b) of this paper; the former giving the value of r with which to enter a table of radii to obtain D°, and the latter giving the value of q when r is known.

In my investigations concerning the laws of the transition curve and its relations with connecting circular curves, I was for the most part without guide or beacon, and it is therefore very satisfactory to find that the "exact solution" of Professor Cain is, as far as it goes, a practical endorsement of the general methods and special formulas which were developed by me in the "approximate" solution.

Arthur N. Talbot, M. Am. Soc. C. E.—It is to be regretted that Mr. Ward did not include in his paper a fuller statement of the conditions fulfilled and unfulfilled, in order that those not mathematically inclined might not be misled. The method described for putting a transition curve in existing track is really the same as that used by the ordinary trackman who throws the track in at the P. C., and thus eases the curve. However, it must be borne in mind that the last fourth of the easement length as given by Mr. Ward's method will be of sharper curvature than the main curve, and that the transition curve at the connecting point will be of one-third greater degree than that of the main curve. Thus, if a 9° curve were joined with 200 ft. of such a transition curve, this transition curve would be a 9° curve at 150 ft. from the point of transition curve, a 10° 30′ at 175 ft., and a 12° curve at the point where it connects with the main curve, joining at once with the 9° curve. It must be further borne in mind that to make a change in the old P. C. sufficient to secure an efficient easement, a transition curve must be used of even greater length than Mr. Ward apparently recommends.

In the method given for new work the condition named that the offset GH (Vol. XXVII, Fig. 2, p. 19) shall not exceed one-fourth of the ordinate AH is not at all necessary, and a somewhat larger value

than one-fourth will give a more efficient easement than values less than one-fourth. The best results are obtained with $GH = \frac{1}{4} AH$.

Again, Mr. Ward errs in calling the resulting curve a cubic parabola, since in the method for old track and in most of the demonstration for curves for new work, he measures and uses the distances along the curve rather than along the tangent. As such, it is the real transition spiral whose radius varies inversely as the distance along the curve, rather than the cubic parabola which only approximates to that. The last two formulas on page 19 are approximations which bring in the cubic parabola. It may be noted that at the connecting point the tangent to the main curve and that to the cubic parabola put in by the last method will not coincide. In example (2) on page 20, they will diverge 25′. While this is not so great a discrepancy as may occur in some actual cases, it may be avoided by using the distances measured along the curve in the way distances are measured on circular curves.

The continued use by engineers of the term cubic parabola in connection with this easement is indefensible on the score of simplicity in use and demonstration, as well as of mathematical correctness. The investigation of the cubic parabola in reference to its change of curvature, its angle turned, the angular deflection to points on it, and the length of the curve, require as long mathematical equations as those governing the transition spiral. In the transition spiral, the distance used is the distance along the curve measured by chords as in circular curves, the angular change of direction and the deflection angles vary as the square of this distance, and the curve may be run in by a process similar to that for circular curves.

As the equations for the transition spiral may not be generally known, a summary of them without demonstration may be of value.

The following nomenclature will be used:

D = degree of curve of the spiral at any point, called D_1 at the end of spiral, and becoming D_0 of the main curve.

n = number of 100-ft. stations from the point of spiral along the curve to any point on the spiral, called n_1 for the whole spiral.

Δ = angle between the initial tangent and the tangent to the spiral at the given point. For the whole spiral call this Δ_1.

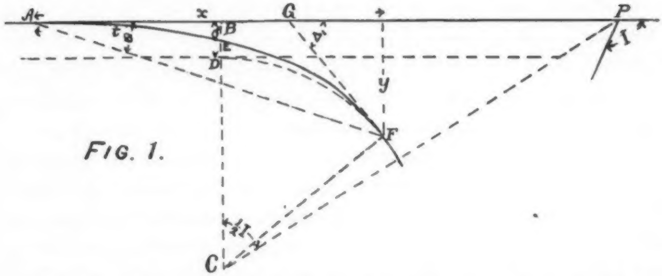

FIG. 1.

$\Theta =$ deflection angle (BAF, Fig. 1) at the point of spiral, from the initial tangent to any point on the spiral.

x and y are coördinates.

$o =$ offset or shift BD between initial tangent and the parallel tangent of main curve produced.

$t =$ abscissa (AB) of P. C. of main curve.

$a =$ degree of spiral at 100 ft. from point of spiral. This shows the rate of change of the curvature of the spiral.

The principal equations are—

$D = an$	becoming	$D_1 = an_1$	for whole spiral.
$\varDelta = \frac{1}{2}\, an^2$	"	$\varDelta_1 = \frac{1}{2}\, an_1{}^2 = \frac{1}{2}\, n_1 D_1$	" "
$\Theta = \frac{1}{3}\, \varDelta = \frac{1}{6}\, an^2$	"	$\Theta_1 = \frac{1}{6}\, an_1{}^2$	

$o = .07\frac{1}{4}\, an_1{}^3 = .07\frac{1}{4}\, D_1\, n_1{}^2.$ " "

$t =$ half length of spiral in feet — $.0001\frac{1}{4}\, a^2 n_1{}^5$.

$x =$ length of spiral to any point in feet — $.00075\, a^2 n^5$.

$y = .291\, an^3$. For values of $\varDelta$ greater than 15° this value of y is in excess $.0000016\, a^3 n^7$.

The principal properties of the transition spiral may be stated as follows:

First.—The degree of curve at any point on the spiral equals the degree at 100 ft. from the P. S. multiplied by the number of stations to that point; thus, if $a = 2$, at 100 ft. from the P. S. the spiral will be a 2° curve; at 25 ft., a ½° curve; at 450 ft., a 4½°. Likewise the total length will be $\frac{D_1}{a}$. If $a = 2$, a 6° curve would require a spiral three stations long.

Second.—The angle $\varDelta$ between the initial tangent and any point on the spiral (the change of direction corresponding to the central angle of circular curves) in degrees, equals one-half the degree a, at 100 ft.,

multiplied by the square of the length in stations; or it is one-half the angle for a circular curve of the degree of the spiral at the given point. Thus, if $a = 2$, for 300 ft. $\Delta = 9°$; while as D will be 6° at 300 ft., the same length of circular curve would give 18°. In other words, the spiral is twice as long as a circular curve.

Third.—The deflection angle Θ at the P. S. from the initial tangent to any point on the spiral is $\frac{1}{3}\Delta$, or $\frac{1}{6}an^2$, or one-third of the deflection angle for a circular curve of the same degree as the spiral at the given point. This may be used in the convenient form—angle in minutes equals $10\,an^2$. The value of Θ is slightly in excess of the true value for large angles, but for Δ less than 20° it is within the limit of accuracy of field work, and for $\Delta = 15°$ the formula gives only 0′.2 excess.

Fourth.—The angle AFG (Fig. 1) $= \Delta - \Theta = 2\,\Theta$. This allows the main or circular curve to be run in from a backsight on the P. S.

Fifth.—It may be shown that the spiral diverges at any point from its osculating circle (circular curve of the same degree) at the same rate that the spiral deflects from the initial tangent, both in regard to distance and to angle. This enables the spiral to be located by offsets measured from the circular curve or by a transit set anywhere on the spiral.

By the former method, half of the curve AE may be located by offsets from AB, and the half EF by the same offsets from the circular curve FD at distances measured from F.

By the latter method, the deflection angle from a tangent at the transit point on the spiral to any other point on the spiral (as CBH,

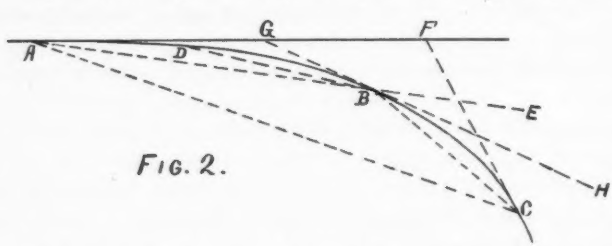

FIG. 2.

Fig. 2) is the sum or difference of (1) the deflection angle for a simple curve of the same degree as the spiral at the transit point for a length equal to the distance between the two points, and (2) the spiral deflection angle Θ for the same length of spiral as the distance between the

two points. Thus, if $a = 2$ and the transit be at B, 250 ft. from the P. S., the degree of curve at the transit point will be 5°, and the deflection angle CBH to set a point 150 ft. ahead will be 3° 45′, ($\frac{1}{2}$ of 150 ft. of 5° curve) + 45′, (spiral deflection angle for 150 ft., $10 \times 2 \times \overline{1.5}^2$) or 4° 30′. For D, 150 ft. back, it would be 3° 45′ — 45′ = 3° 0′.

Likewise the angle CBE may be calculated by adding the Θ for the point C (GAC) to $\frac{1}{6}$ the product of the degree of curve at B by the number of stations in AC. In the example cited this will be ($\frac{1}{6} \times 2 \times 4^2 = 5° 20′$) + ($\frac{1}{6} \times 5 \times 4 = 3° 20′$) = 8° 40′. For the point D, ($\frac{1}{6} \times 2 \times 1^2 = 20′$) + ($\frac{1}{6} \times 5 \times 1 = 50′$) = 1° 10′. This enables the deflections from the tangents at P. S. to be used for other transit points by the addition of $\frac{1}{6}$ Dn, when D is the degree of curve at the transit point.

This property is of value in mountainous districts or when curves are run in for trestles, etc.

Sixth.—The middle ordinate of any arc of a spiral is the same as that of a circular curve of the same length and of degree equal to that of the spiral at the middle point of the arc considered.

Seventh.—The long chord AF (Fig. 1) equals the length of the curve in feet minus .0004 a^2n^5.

Eighth.—The offset o is approximately $\frac{1}{4}$ of the ordinate y of the end of the spiral. The spiral bisects the offset at a point halfway between the P. S. and the P. C. C. ($AE = EF$. $BE = ED$).

Ninth.—The ordinates from the initial tangent vary as the cube of the distance along the spiral from the P. S. Likewise the offsets from an osculating curve at any distance from the point of contact are equal to the ordinates at the same distance from the P. S.

If the tangents have been run to an intersection, the distance from the apex to the point of spiral will be the ordinary subtangent, plus the t given above, plus $o \times$ tan. $\frac{1}{2}$ total intersection angle. In case a simple curve has been run, the point of spiral will be at a distance back of the P. C. equal to t, plus $o \times$ tan. $\frac{1}{2}$ total intersection angle. The field work is then similar to that of circular curves. Since it is not necessary to make succeeding chords the same length as the first, the usual stationing may be kept up. It is advisable that when the spiral becomes sharper than 7°, chords as short as 50 ft. be used. A table for the deflections and ordinates may easily be made, or the

powers of n may be taken from a table of squares and cubes, and the lower decimals dropped, and the multiplication by the simple factors may be made easily and rapidly. Thus, when $a = 2$, to determine Θ for 234 ft. (2.34 stations) from the P. S. find the square of 234, (54756), change the decimal point so that it will become the square of 2.34, (5.48), and since Θ in minutes equals $10\ an^2$, $\Theta = 10 \times 2 \times 5.48 = 109'.6 = 1° 49'.6$. For o and y the table of cubes may be used in a similar way. For a transit point on the spiral use the principle given in (5).

The value of a to be used will generally depend upon considerations of length of tangents and speed of trains. For 3° to 8° curves it may range from 1 to 4; for 6° to 12°, from 2 to 10; for sharper curves, higher values. If it is desired to connect a given tangent with a given curve, the offset o being known, the following formulas may be used:

$$a = .269\sqrt{\frac{D^3}{o}},\ n = 3.714\sqrt{\frac{o}{D}}.$$

If for a desired offset o, a is found to be fractional, a convenient value may be chosen and a length n used which will give the desired offset. Thus, for $o = 9.0$ and $D = 8°$, $a = 2.02$. Using $a = 2$, in order to make $o = 9.0$, the length $n = 2.4\sqrt[3]{\frac{o}{a}} = 3.96$, and the spiral at the end is a 7°.92 curve, compounding with an 8° curve.

Old Curves.—To replace a simple curve by a spiral and new curve without varying far from the old line, proceed as follows: Let p be the distance it is desired to throw the track outward at the middle point of the curve in order to replace it by spirals and a new and sharper curve. Let I = total intersection angle. The radius of the new curve must be shorter than the old radius by $o + \frac{o + p}{\text{exsec.} \frac{1}{2} I} = \frac{o + p}{\text{vers.} \frac{1}{2} I} - p$. If $p = 0$, this reduces to $\frac{o}{\text{vers.} \frac{1}{2} I}$. The point of the spiral will be a distance back of the old P. C. equal to $t - (o + p)$ cot. $\frac{1}{2} I$. 0 to $\frac{1}{2}\ o$ will give good working values for p. If the new curve comes inside the old at the center, p must be used as negative in the preceding formulas. It is usually sufficient to use for the spiral only the length that would fit the original curve, but the formulas are good for any length of spiral. As an example, take $I = 60°$, $D = 6°$, $a = 2$. Then o for a 6° curve is 3.93. Take $p = 1.0$, approximately.

The radius of new curve must then be 36.7 ft. shorter than the old. The curve may then be run by using 300 feet of spiral, compounding with a 6° 14′ curve. If it is desired to have the spiral more nearly agree with the main curve, a value of o corresponding to $D = 6° \ 14'$, or a little greater, may be computed and a new curve found.

In case it is desired to leave the greater part of a long curve untouched, a sharper curve (say not to exceed 10% sharper) may be compounded at the ends of the main curve and the spiral attached to this. Then $(R_1 - R)$ vers. $\Delta = o$, where $\Delta =$ angle of a spiral plus angle of new curve. Thus, for a 6° main curve, compound with a 6° 30′ curve. Then by the formula, $\Delta = 21° \ 17'$. if $a = 2$. For $D_1 = 6° \ 30'$, the angle of the spiral is $10° \ 34'$, $21° \ 17' - 10° \ 34' = 10° \ 43'$. Hence, run in 325 of spiral, then 10° 43′ of 6° 30′ curve, and compound with the old 6° curve.

The preceding methods have generally been based upon the principle that the spiral is to be of the same degree of curvature at the end as the main curve, and will need slight modification when not so. If the D_0 be the degree of the main curve and n_0 the length in stations of 100 ft. from the point where the spiral joins to the old P. C. or point where the tangent to the main curve produced becomes parallel to the initial tangent, then $\frac{1}{2} n_1 D_1 = n_0 D_0$. $o = y - R$ vers. $\Delta = y - .873 \, n_0^2 D_0$. $y = .291 \, n_1^2 D_1 = .582 \, n_1 n_0 D_0$. $n_1 = \dfrac{y}{.582 \, n_0 D_0} = 1.718 \dfrac{y}{n_0 D_0} = 1.718 \dfrac{o}{n_0 D_0} + \frac{3}{2} n_0$, which is the same form as Mr. Ward's final equation.

By Mr. Ward's method for old track, o will be 0 and $n_1 = \frac{3}{2} n_0$. Likewise by substituting in the first equation $D_1 = \frac{4}{3} D_0$.

The principles that the deflection angles vary as the square of the distance along the curve and that the ordinates vary as the cube of this distance remain true, no matter what the relation at the connecting point, and hence Mr. Ward's method in this particular is correct.

Muenscher's Method.—By making the length of spiral uniformly 200 ft., as proposed by Mr. E. W. Muenscher, the necessary formulas are quite simple and the lengths of spiral are fairly well suited to ordinary railroad curves. The following formulas follow directly from the preceding by making $n_1 = 2$: $\Delta_1 = D_1$. $a = \dfrac{D_1}{2}$. $o = .29 D_1$. $t = 100 - .001 D_1^2$ or 100 ft. for D_1 less than 10°. $y_1 = 1.16 \, D_1$. Other ordinates are proportional to the cube of the distance.

The transition spiral herein outlined is in reality the same as that used by Howard as reviewed by Professor Cain in the *Transactions* for May, 1892. For proof of the principles and a further discussion of the use, together with tables, see an article in Technograph No. 5 of the University of Illinois, page 77.

The question of the efficiency of easement curves is of considerable importance. The objection is sometimes raised that even if track is laid out with a carefully fitted spiral there would be no possibility of keeping it in place by the methods of the ordinary trackman. This identical objection could be made with the same force against carefully laid-out circular curves, yet no engineer would recommend abolishing that practice. Even if, in re-lining, the transition curve is considerably distorted, it remains an easement, and will be in far better riding condition than a distorted circular curve. By marking the P. S. and the P. C. C. with a stake or post, with possibly an intermediate point on long spirals, the trackman will be able to keep the spiral in as good condition as though it were of uniform curvature.

Properly constructed spirals would frequently allow the use of sharper curvature—since the riding quality of curves may be the governing consideration in the selection of a maximum—and thus make a saving in construction. By fitting curves with proper transition spirals, roads using sharp curves may partially relieve the objection of the public to traveling by their routes. The transition curve has, then, a financial value largely overbalancing its cost. The adoption of such curves by many of our principal railways proves their efficiency, and the future will see a much more general adoption.

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COMBINATION BRIDGES—DISCUSSION ON PAPER No. 557.*

By MENDES COHEN, M. Am. Soc. C. E., and WILLIAM A. AYCRIGG, Assoc. M. Am. Soc. C. E.

MENDES COHEN, M. Am. Soc. C. E.—It may not be uninteresting for the Chair to give a reminiscence of one of the earlier combination bridges.

In the construction of the extension of the Baltimore and Ohio Railroad west of Cumberland the Chief Engineer adopted what he termed combination bridges, in which the compression members were of timber, and possibly some of the tension members also, as I do not recollect the form of the truss. What I do recall, however, is that there was a supplementary system of bracing of iron bars, forming a catenary.

The first of these bridges crossed the Potomac on the 21st mile west of Cumberland, and when this section of the road was opened in July, 1851, I was present with the excursion party. On reaching this

* "Combination Bridge Building on the Pacific Coast," by Alfred D. Ottewell, Esq., Vol. xxvii, page 466.

bridge the train was stopped, and the excursionists were invited to examine the new structure. This we did and the train was moved over it, I suppose to show its stiffness. I followed the example of some of my seniors, and got my eye down to the level of the track, not knowing much about what was to be expected, but I have recently had my memory refreshed as to what occurred. When the locomotive, a 25-ton Camel engine, entered on the bridge, it deflected the structure to such an extent as to alarm some of the onlookers, who exclaimed, "It's going down." To this Mr. Latrobe could only assure them there was no danger. However, the wave under and ahead of the train was very marked, and sent a tremor through the nerves of many who had less confidence than the Chief Engineer.

The bridge stood under its work for several years before giving place to a structure entirely of iron.

H. B. Seaman, M. Am. Soc. C. E.—Were not the first Bollman's combination bridges?

Mr. Cohen.—No, the first Bollman bridge was the structure at Harper's Ferry, which was called the Winchester Span of the Harper's Ferry bridge. My recollection is that it was entirely of iron; the chords and posts were of cast iron.

I am not quite sure that some of Mr. Fink's earlier bridges may not have had the compression members of wood; I am not sure of that, but I am inclined to think that some of the smaller spans had.

Wm. A. Aycrigg, Assoc. M. Am. Soc. C. E.—I was called upon some time ago to examine a combination railroad bridge in the eastern part of Pennsylvania. This bridge was built in 1879, and was a single track, through, double triangular truss. There were five spans of 146 ft. and one of 73 ft., 19 ft. deep, and panels 12 ft. 2 in. long. The top and bottom chords and struts were wood, ties and counters were iron. The bridge was rather peculiar in one respect. The piers were stone, and at each pier there were very heavy brackets running out a little past the middle of the end panels. I was at a loss for some time to understand why the brackets were put there, and the only reason I can give is that the designer simply intended them to keep the bridge from sliding off the piers. The details of the bridge were remarkably poor. The ends of the struts simply rested against cast-iron angle blocks, set three-quarters of an inch into the chords. The angle blocks had nothing but this three-quarters of an inch of wood to hold them in place,

and assuming that the horizontal component of the stress in the struts was resisted entirely by this three-quarter inch multiplied by the width of chord, I found at some panel points a unit-crushing stress as high as 5 000 lbs. and at all such panel points, and in fact at panel points where the crushing amounted to only 2 500 lbs., the wood showed signs of giving way. The jar of a passing train would cause the struts to move a little off the angle blocks, and about once every month the bridge carpenter would drive them back. The ties rested upon the bottom chord, and as the unit stress in this member at the center of the bridge was as high as 2 500 lbs., it would seem that the designer had entirely neglected the bending. This bridge, I am happy to state, has been condemned and will soon be replaced by an iron structure.